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(6) THE SAN FRANCISCO BAY - DELTA

WASTEWATER AND RESIDUAL SOLIDS

MANAGEMENT STUDY.

(11) Aug 72

(12) 301p.

VOLUME III.

Technical Appendix.

Wastewater Residual Solids
Management Study.

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San Francisco, CA

4103

The San Francisco Bay - Delta
Wastewater and Residual Solids
Management Study

Volume III- Technical Appendix
Wastewater Residual Solids Management Study

Prepared for:
The San Francisco District
U. S. Army Corps of Engineers

PBQ&D, Inc.
San Francisco, California

August 1972

The San Francisco-Bay-Delta Wastewater and Residual Solids Management Study

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A. INTRODUCTION

A. INTRODUCTION

The objectives of the San Francisco Bay - Sacramento and San Joaquin Delta 12-County Regional Wastewate. Residual Solids Management Study (Portion I) are to develop a summary and projection of systems methodology for wastewater sludge and residual solids handling and land disposal within the confines of a larger 43-Central California Counties Study Area. The Study Area includes the entire Central Valley and Monterey Bay region together with the Bay - Delta Waste Source Region. It has been amply described in Technical Appendix Volume II (see Section II-A-1 and Figure II-A-1).

This study is closely associated with several San Francisco Bay - Delta Wastewater Land Disposal Management studies which together supplement the work of the San Francisco District of the U. S. Army Corps of Engineers in their integrated Pilot Wastewater Management Program survey-scope and Triple "S" water quality management planning efforts for the San Francisco - Sacramento - Stockton region, most specifically that covered in Technical Appendix Volume II of this report. Further background is given in Section II-A-2, "Previous Studies."

This study consists of a comprehensive literature search into the current state-of-the-art of sludge and residual wastewater solids management as it applies to land disposal of these solids within the study region. Various methods and unit processes and operations, current and experimental, have been evaluated as to their characteristics, availability, processing and application rates, end products and relative costs.

The most general criteria governing this and companion studies are those stated in the broad general welfare promotion, land-use pattern development, and environmental and water quality protection and enhancement policies and standards of the nation, the State and the San Francisco Bay - Delta region (Refs. 1-5,120,130,182-185,193).

In this study, PBQ&D, Inc. was specifically assisted by the services of Kennedy Engineers, Inc. of San Francisco. Kennedy Engineers was predominantly responsible for the information in Chapters B, C and F concerning sludge and residual solid characteristics, volume reduction and sludge recycling, respectively.

B. SLUDGE AND RESIDUAL SOLIDS CHARACTERISTICS

B. SLUDGE AND RESIDUAL SOLIDS CHARACTERISTICS

1 - General

Sludge is a term which refers to the settleable or otherwise separable waste solids found in water, wastewater or other water-borne process streams and which are separated or removed from these process streams together with an accompanying mass of water. 1/ It has been further defined as a semi-liquid waste having a total solids concentration of at least 2500/ppm, i.e., at minimum of 0.25% dry solids (Ref. 154). The term generally includes all but the largest of the solids removed. In this report, the term will often refer to all wastewater solids removed from the wastewater process stream. These include:

1) Screenings,
2) Grit,
3) Skimmings, primarily oil and grease,
4) Organic solids sludges,
5) Lime sludges,
6) Toxic solids, and
7) Regeneration solids.

In this report, the term will also not be confined to the semi-liquid or highly dilute slurry state. This report, Technical Appendix Volume III, also assumed the continued use of the activated sludge system in secondary treatment, the assumption also of Volume II.

Wastewater solids vary in their characteristics both daily and seasonally and from one system to another. Summaries of these characteristics, therefore, must be based on ranges in values and some degree of generality. A summary of these ranges is presented in Table III-B-2 found at the end of this chapter. Estimates of quantities for the 12-county San Francisco Bay - Sacramento and San Joaquin Delta Region, for the year 2000, are presented in Tables III-G-1 and III-G-2. Changes in technology and pertinent control regulations can introduce drastic changes in solids quantities and qualities within a system. The introduction of household garbage grinders, for example, has resulted in up to 30 percent increases in publically collected volatile solids, primarily in the organic sludges. In those communities permitting commercial garbage grinders, additional increases have also been noted.

1/ General references for this Technical Appendix III Chapter include: 6, 9, 24, 29, 30-34, 123, 154.

Communities with seasonal food processing industries have wide ranges of solids loadings. Communities which have adopted realistic industrial waste revenue charges have experienced significant reductions in solids. Communities with combined sewer systems usually have higher grit loadings as well as greater variation in organic solids flows due to flow variation, settling and resuspension of solids in the large pipelines.

Wastewater solids require different handling methods depending upon their water content and physical characteristics. These characteristics can be classified as follows:

a) Granular. A material which is composed of discrete, generally uncemented particles capable of being handled in bucket elevators, conveyors, pneumatic ejectors and similar solids handling devices. With high water content, granular solids can be pumped with suitable pumps.

b) Liquid. A material which generally flows in pipes and can be moved by pumps or by pneumatic ejectors.

c) Semi-Liquid. A viscid liquid which frequently becomes more liquid on heating. When its viscosity is controlled or overcome, it can be pumped.

d) Thixotropic. A gelatinous solid that liquifies on vibration and can be pumped with plunger pumps, centrifugal pumps with plunger pumps in paralled or some positive displacement pumps. It generally liquefies on dilution.

e) Semi-Solid. A material that tends to settle and resist resuspension, such as fine silt and lime sludges. If kept suspended, it can be pumped, but when dewatered it can be handled like granular solids.

f) Heterogeneous. A material of no characteristic shape or form. It requires a combination of handling techniques to accommodate liquid and solid constituents.

2 - Screenings

Screenings are the first fraction of wastewater residual solids removed from the secondary wastewater process stream. They are a minor fraction of these residual solids. They account usually for under 0.5 percent (on a dry weight basis) of the total mass. Typical secondary-level treatment systems, it should be noted, are those which remove about 90 percent of the wastewater's major suspended matter and about 90 percent of its combined dissolved and suspended organic materials, the latter expressed usually in terms of the 5-Day Biochemical Oxygen Demand (BOD) which the putrescible organics can exert.

Screening is a process of removing the largest solids to be found in water, wastewater, or other process streams by means of passing the flow through devices with variously spaced or sized uniform openings. The size of the openings will determine what size of materials will be removed. Screening devices range from the coarse parallel-spaced bar racks to fine mechanically driven screens and are often associated with cutting or shearing devices for physical size reduction of many of the bulky floating and suspended solids. The purposes of screening are to (1) protect pumps, piping, valves and nozzles from damage and clogging by these trashy solids, (2) to remove materials which would interfere with or reduce the efficiency of subsequent processing or treatment, and/or (3) to remove materials that would contribute to the unsightliness of receiving waters.

Screenings which are removed by bar screens at treatment plant headworks include rags, wood and metallic materials, rocks, plastics, and large organic materials. Considerable amounts of smaller organic solids adhere to these larger inorganic materials and are also removed. Screenings are usually drained as removed. They have the consistency and moisture content similar to wet garbage. They can be further dewatered by pressing if this is justified. Screenings can be ground, comminuted or mascerated, and returned to the process stream for subsequent removal and treatment as part of the organic solids fraction removed as sludge. In this latter case, they would add to scum accumulation in primary sedimentation tanks.

Screenings are of irregular sizes and shapes and frequently have high water contents. Because of their organic content, the material is putrescible and best handled in closed watertight containers.

In general, all screenings are handled as an in-plant operation and are rarely transported for substantial distances. They are often disposed of with the organic sludge from the plant. In this case their quantity and cost of disposal would be included with the organic sludges.

Open storage and conveyances for screenings are objectionable because of odor and insect breeding. Covered refuse cans, conveyors or pneumatic ejectors are preferred for conveyance, but the distance is kept as short as possible. All mechanical methods of handling have some difficulties; belt conveyors probably have the least.

The amount of material removed depends on bar screen spacing and the source of waste flows. Based on an observed value of effective density of 60 pounds per cubic foot at 80 percent moisture, removal quantities of wet screenings in cubic feet per million gallons (cf/MG) and total dry screenings solids in pounds/MG would usually fall in the following ranges:

	cf/MG	lbs/MG
4 inch bar spacing:	0.1 - 0.5	1.2 - 6
2 inch bar spacing:	0.25 - 1.5	3 - 18
1 inch bar spacing:	3 - 8	36 - 96

Incineration is considered the most satisfactory method of disposal for screenings although burial without prior volume reduction by incineration is often employed. Since grinding and return of screenings to the raw wastewater contributes to the accumulation of scum in primary tanks and digesters, many plants dispose of screenings separately by simple burial or incineration and subsequent burial of the ash residue. These latter operations are sometimes combined with those for disposing of garbage and other refuse materials. Screenings may be transported directly to a sludge incinerator and fed in with the dewatered sludge. In burial operations, lime is often added for odor, insect and rodent control.

3 - Grit

Grit is the second fraction of wastewater residual solids removed from the wastewater process stream. It is also a minor fraction of these solids. It accounts for roughly up to 30 percent (on a dry weight basis) of the total residual solids separated from the wastewater process stream in typical secondary-level treatment systems.

The term is loosely applied to the larger and very rapidly settleable inorganic solids which pass through the bar screens and are subsequently removed from the process stream. In practice the grit removed includes some organic matter such as coffee grounds, corn, grease, ground plastics, paper and wood, and some putrescible fecal solids together with sand, gravel and smaller metal and glass particles. When high concentrations of larger and more easily settleable putrescible organic materials are included, the material is usually referred to as

detritus. Washing to remove these organics tends to wash out the smaller sand fractions, thus returning them to the process stream where they are subsequently removed with the organic solids in the sedimentation tanks.

Grit is normally removed at plant headworks in a controlled velocity basin which allows most light organic solids to pass through but settles out the heavier solids. The grit is washed to remove free or entrapped organics and is then stored for later disposal. Some plants now make further grit separation from organic sludges by centrifuging, which is part of the sludge concentration process. These latter grits are usually of fine particle size and are virtually free from organics.

Grit quantities vary widely between combined sewer systems and separate sanitary sewers and are influenced by sewer infiltration, soil characteristics and the prevalence of garbage grinders. Combined sewers may produce between 10 and 80 cubic feet of grit per million gallons (MG.) depending on rainfall, sewer condition and other factors. Separate sewers produce between one and 18 cubic feet per MG. This amounts to a range of 90 to about 7,200 pounds of dry grit solids per MG.

Grit removed from wastewaters or storm drainage, washed and drained, contains approximately 30 to 60 percent moisture and 20 to 40 percent organic matter. Normally, this is all the pretreatment the grit will receive before being transported to a loading dock for transportation. Depending on the environment of the disposal area and the method of handling, the grit may require further treatment before ultimate disposal. For example, if the grit is to be used for roadway surfacing or landfill in areas where its organic content might become a nuisance, it should be cleaned in a special washer to less than 10 percent organic matter; or it should be incinerated with other refuse or sludge and be disposed of with the ash from the incinerator. Because of its grease and organic content, grit is readily putrescible and rapidly produces noxious odors when stored without prior stabilization of some type. Lime is usually used for this odor control.

Grit may be transported by belts, bucket conveyors, hand wheelbarrows or small trucks for short in-plant distances. For distances more than 200 feet, trucks are usually used to transport the grit to points of disposal. Since the quantity of grit from a single plant and the distances to adequate and acceptable points of disposal or use are usually short, the problem of grit transport and disposal is usually minor.

Grit from sewage treatment plants is seldom transported in a pipeline because of the abrasive action on pumps and pipelines even

though a 80 percent water mixture could be pumped. Mixed with other materials or sludges, it may be transported as a slurry in pipelines to any desired distance. Dewatered grit is usually granular with water content up to 60 percent.

Grit may be transported by truck, rail or barge in much the same manner as the other solids. Stabilization by incineration or addition of lime may be required to control odor for transport and handling.

Grit can be satisfactorily disposed of by sanitary landfilling, incineration and landfilling of ash and grit residue, or by means of composting. The nature of the grit often influences the method of ultimate disposal. Burial or composting is frequently used to control odor, insect and rodent problems. Larger and more modern installations often dispose of grit and screenings by incineration with the ash being utilized as landfill or for roadway surfacing.

4 - Oils and Grease

Oils and grease together with minor amounts of other scum materials, fibrous floating trash and other miscellaneous floating materials are removed from the wastewater process stream as skimmings, the third fraction of wastewater residual solids. They, as screenings and grit, are also a minor fraction of these solids. They account for roughly 7 to 8 percent (on a dry weight basis) of the total residual solids separated from the wastewater process stream in typical secondary-level treatment systems.

Oils and grease removed in wastewater treatment processes are composed of:

1) Vegetable and animal fats,
2) Petroleum oils and solvents,
3) Synthetic oils (cutting oils, etc.)

Vegetable and animal fats present the least problem as they are readily degradable or combustible and can be digested in treatment processes with gas production as a by-product. It is estimated that about one-third of these fats originates from domestic sources. The remainder originates from industries which may elect to salvage the majority of the material under economic pressure of increased sewer rates.

Petroleum oils and solvents and synthetic oils come from illegal dumping, accidental discharges and floor drainage. Illegal dumping is probably the major source and is almost impossible to prevent. Solvents present a fire and explosion hazard. The oils inhibit treatment processes and the synthetic oils are toxic to biological and digestion treatment.

The quantity and quality of scum varies widely from day to day. Both the quantities of oils in wastewater and the percentages removed have been increasing in the last few decades. The increase is due to decreased saving of greases together with the increased use of detergents which facilitates oil and grease emulsification in sewers. Normal domestic wastes now average about 60 mg/l oil and grease, but industrial wastes can be as high as 500 mg/l. It is anticipated that enforcement of State and Federal industrial wastewater control ordinances will reduce levels to a maximum average of 150 mg/l. Oils and grease are removed from the wastewater flows by skimming, aeration, chlorination and chemical treatment. Up to 50 percent of the total oil and grease content of raw wastewater is removed with grit and screenings. New treatment plants using anthracite filters are obtaining over 98 percent oil and grease removal. Dewatered skimmings are about 50 percent oil and grease with the remainder being organic solids and water. It is estimated that skimmings will range from 260 pounds per mg. for domestic wastewaters to 2,200 pounds per mg. for industrial wastes.

Mechanical skimming devices are reasonably reliable and adequate but must be supplemented with considerable hand labor. Usually, the skimmings are discharged into the sludge handling facilities. Normally these skimmings are liquid and can be pumped. The tendency to encrust and plug pipelines requires close operational control. Consequently, in-plant pipelines are made as short as possible and are provided with cleanouts and facilities for cleaning the lines when they become plugged with grease. Pumps used for scum are usually of the pulsating positive displacement type. Because of the high organic content, putrefaction and gas formation is a problem.

Investigation has indicated that animal and vegetable oils and even petroleum oils can be degraded when applied to aerated soil under favorable temperature and humidity conditions.

Grease is consumed to a considerable extent in the sludge digestion tanks, but mineral oils are relatively inert. Both contribute to the heavy layer of scum commonly found in digesters. Since greases and oils coat and plug pipelines and are a nuisance in digestion tanks, it is desirable to dispose of the materials separately, and immediately upon collection. Commercial burners are available that will use the

grease and oil as fuel for heating or other useful purposes such as steam generation for small power, supply or steam cleaning.

Scum, which is skimmed from the top of treatment process tanks, consists for the most part of oil and grease. This material has a very high heat value and can be added to the organic sludges to aid combustion during incineration processes. It is also possible to burn screenings and scum in a separate incinerator specifically designed for that purpose, as is the practice in Minneapolis-St. Paul Sanitary District (Ref. 96).

Like screenings, scum is usually disposed of within the plant site, and is rarely transported away from the plant. The quantities are not large enough and the quality too poor to have a commercial value. Scum cleaned by processing to remove the other materials entrained in it would be handled and transported by trucks in open tanks or oil drums to a point of use outside the plant. However, this processing would cost more than the present commercial value of the material.

5 - Lime Sludges

Lime sludges are produced by high-lime treatment of phosphate and residual secondary effluent organics removal. This treatment is a tertiary-level process. Lime sludges are the most voluminous of the chemical sludges which can be produced with tertiary or "advanced waste treatment" generally and with tertiary treatment for phosphorous and residual organics removal specifically. Alum-iron sludges, for example, would generally be less than half the amount produced with high-lime treatment. Only demineralization processes could produce sludges in amounts exceeding that of high-lime treatment, the degree depending on the Total Dissolved Solids removed. One mg/l removed equals 8.34 dry pounds per million gallons. No plants in the Bay Area now have such treatment, but at least one (the City and County of San Francisco) proposes such treatment. It would consist of 300 to 500 mg/l of lime addition (as CaO), the sludges being produced ranging from two to three times this lime addition depending on whether sea water is also added to facilitate removals. If high-lime treatment were employed throughout the 12-county waste source region, lime sludges would become the major wastewater residual solids fraction. Estimates summarized in Table III-G-1 indicate that lime sludges would amount to about 1.7 times all other typically secondary-level residual solids combined (on a dry weight basis) and overwhelm the organic sludges by more than 2.5 times.

Tertiary high-lime treatment reportedly (Ref. 195) can remove about 95 percent of the phosphorus, 88 percent of the total suspended solids, 86 percent of the biochemical oxygen demand, 62 percent of the chemical oxygen demand and 74 percent of the total organic carbon from secondary-level treated wastewaters. The process also simultaneously reduces hardness and alkalinity, respectively, by precipitating out magnesium hydroxide and calcium carbonate. Minor amounts of iron, manganese, strontium, aluminum, borates and silicates are also removed to the extent they are present. This and the information in Table III-F-1a indicates the composition of lime sludges.

Lime sludges can be readily dewatered by filter or centrifuge to about 50 to 70 percent water content. While these solids can be disposed of by fill or incorporation in sludge composting, they have more value in recalcining, separation and recovery of a major portion of the lime. Recent research has indicated technical feasibility of recovery of phosphates from lime sludges for agricultural use. For land disposal this lime sludge could be applied as a soil amendment, the same as lime or limestone. Experience in handling such a mixture is limited but it appears feasible to pump it as a slurry or to handle it as a liquid in tank trucks, tank cars or tank barges. Recalcining lime sludge for reuse is practiced at several larger water softening plants.

The quantity of lime sludge can range between 5,000 to 13,000 pounds per million gallon of wastewater, depending almost exclusively on alkalinity (Ref. 215). About 25 percent of the total lime sludge can be recovered as lime. This corresponds to approximately 75 percent of the lime added (Ref. 195). The remainder must be disposed of in some manner.

6 - Organic Solids

Organic solids are the fourth and the major fraction of secondary wastewater residual solids removed from the wastewater process stream. They account for roughly 60 to 70 percent (on a dry weight basis) of the total residual solids separated from the wastewater process stream in typical secondary-level treatment systems. The organic solids sludges are composed of the suspended and larger colliodal organic waste solids typically removed from the process stream in the primary and secondary sedimentation or settling tanks or clarifiers together with accompanying sediments, these latter including varying amounts of grit, macerated screenings, entrapped oil and grease, chemical additives such as lime, alumina and iron (when these are used to encourage flocculation and coagulation), toxic solids and solids from regeneration and dewatering processes.

Undigested sludge from plain sedimentation tanks is gray in color, offensive in odor and slimey in texture. Good activated sludge is brown, flocculent and odorless. Septic tank sludge is black, typically putrid in odor, and slightly less slimey than primary sedimentation sludge. Trickling filter humus is grayish-brown, flocculent and inoffensive in odor when fresh.

There are three principal types of raw sludges produced in wastewater treatment plants. These are:

1) Primary sludge - from primary settling tanks,

2) Trickling filter humus - from the secondary (or final) settling tanks of a trickling filter plant, and

3) Activated sludge - from the secondary (or final) settling tanks of an activated sludge treatment plant.

Activated sludge is a term which specifically refers to the flocs or masses of flocculent materials found and developed in wastewater treatment plant aeration tanks which have been designed to keep these flocs in suspension and provide the dissolved oxygen necessary to maintain aerobic biochemical oxidation processes. These flocs consist of micro-biological slimes (or zoogleal masses) generated about suspended particles or developed from and about colonial growths of bacteria and other suspended living micro-organisms together with included precipitated, colloidal and finally divided suspended organic solids. The preponderance of living microbiota in these masses is the basis for the "activated" terminology. The settled floc masses are the activated sludges in the more proper sense.

These sludges may be concentrated by:

1) Resettling the trickling filter humus in the primary settling tanks,

2) Resettling the waste activated sludge in the primary settling tanks, or

3) Concentration of solids in separate thickening tanks.

To render the raw sludge less offensive and more hygienic for ultimate disposal, as well as to reduce its volume, either anaerobic digestion in closed tanks or aerobic digestion in open tanks is employed. Anaerobic digestion is most generally used except in small plants (less than 1 mgd) where aerobic digestion is most frequently encountered. The primary changes of the physical character of the sludge brought about by digestion process are:

1) Reduction in mass - about 50 percent,

2) Reduction in volume - about 60 percent,

3) Concentration of solids - to 5 percent,

4) Elimination of grit - retained in the tanks,

5) Removal of grease, and

6) Homogenation the mixing and stirring action within the digestion tanks.

Organic solids will consist of a mixture of primary and secondary sedimentation tank sludge. The quantity and characteristics of the sludge will vary with the treatment process and the amounts and sources of industrial wastes. The most prevalent type of treatment expected will be some form of activated sludge which will produce sludges of higher water content which will, in turn, require more concentration for disposal. Activated sludge is difficult to concentrate by conventional methods such as gravity sedimentation, flotation, centrifuging or vacuum filtration unless treated with chemicals or heat. Raw sludge is gelatinous and resists filtration or centrifuge concentration unless similarly treated. Primary sludge will have about 5 percent solids while waste activated sludge will have about 2 to 13 percent solids. Mixed solids will be about 4 percent. This can be increased to 6 percent in a thickener, resulting in a 33 percent reduction in the volume of liquid to be handled. Volatile content ranges from 40 percent to 80 percent of the total dry solids.

On a dry weight basis, quantities of raw mixed sludges from activated sludge treatment plants will range from 1000 to 3000 pounds per mg. A 40 to 60 percent reduction of solids can be obtained by digestion and a 40 to 75 percent decrease in water content can be obtained by heat treatment and filtration or centrifuging.

Disposal of sludge can, in part, involve land spreading, composting, drying, use for soil amendment and incineration. The sludge is liquid and readily pumped at concentrations below 6 percent. When concentrated to less than 80 percent moisture, raw sludge is a thixotropic gel which is not readily pumped. Bridging and adhering cause problems in the solids handling processes. Digested sludges of the same water content show considerably less thixotropic characteristics. Heat dried sludges tend to be a fine powder and although readily transported by air, are quite abrasive.

Fluidity and plasticity vary with water content and the nature of the solids. The most fluid is activated sludge with a water content of 98-99 percent. As the moisture content of a sludge is reduced to about 85 percent, a definite thickening can be noted. At 70-80 percent the sludge will no longer flow and is known as sludge cake. At a moisture content of 10 percent, it is as dry as dust.

The characteristics of sludge may be expressed either physically or chemically. Physical characteristics include moisture, density, color, odor, texture, fluidity and plasticity. Table III-B-1 presents the chemical characteristics of various typical organic sludges.

7 - Toxic Solids

Toxic solids are not presently being removed separately from waste-waters. New waste control regulations emphasize required removal of toxic solids at the source. Minor concentrations of trace toxic materials are removed with organic sludges, or lime sludges where that process is used. Toxic solids would typically include phenols and heavy metals, 80 percent and 40 percent respectively being removable with the organic sludges.

8 - Regeneration Solids

Regeneration solids are the finely divided materials removed from tertiary treatment effluent filters and carbon absorption columns in the backwashing operation. The finely divided organic and inorganic solids removed from effluent filters contain some lippoids. These backwashings are normally recycled back into the plant inflow and subsequently the bulk of them are removed with the organic sludges. Under anticipated techniques they will present no special problems.

Table III-B-1

CHEMICAL CHARACTERISTICS OF ORGANIC SLUDGE TYPES
(% DRY BASIS)

Material	Raw	Digested	Activated	Filter Cake Raw	Filter Cake Digested
Volatiles	60-80	45-60	62-75	55-75	40-60
Ash	20-40	40-45	25-38	25-45	40-60
Insoluble Ash	17-35	35-40	22-30	15-30	30-45
Grease and Fats	7-35	3-17	5-12	5-30	7-15
Protein	22-28	16-21	32-41	20-25	14-30
Ammonium Nitrate	1-3.5	1-4	4-7	1.3	1.3-1.6
Phosphoric Acid	1-1.5	0.5-3.7	3-4	1.4	0.5-3.5
Potash (K_2O)	------	0-4	0.86	-----	-----
SiO	------	15-16	8.5	-----	-----
Iron	------	5.4	7.1	-----	-----
Cellulose	10-13	10-13	7.8	8-10	8-12

(From Reference 123)

Table III-B-2

RESIDUAL WASTEWATER SOLIDS CHARACTERISTICS

Types of Residual Solids	Percent Water Content	Percent Volatiles of Dry Solids	Consistency	Volume/MG of Plant Influent	Pounds/MG of Plant Influent Dry Weight Basis	References
SCREENINGS	40-80	20-50	Amorphous (like wet garbage)	0.1 - 1.5 cu. ft.	1.2 - 18 (60 lbs/cf @ 80% moisture (Ref 9)	29, 31
2" bar spacing	---	---	---	0.25 - 1.5 cu. ft.	---	29,31
4" bar spacing	---	---	---	0.1 - 0.5 cu. ft.	---	29,31
1/2"/1"/2" openings	---	---	---	5.5/2.8/0.6 cu. ft.	---	6,31
1/32"-1/4" openings	---	---	---	5-30 cu. ft.	---	24
1/2"-1" openings	---	---	---	3-8 cu. ft.	---	24
1"-2" openings	---	---	---	0.75 - 3 cu. ft.	---	24
3/32" - 3/4" openings	85-95	50-80	---	3.0 - 5.0 cu. ft.	---	154,187
1/2"-2" openings	85-95	50-80	---	0.5 - 6.0 cu. ft.	---	154,187
GRIT	20-60	10-40	Granular	1 - 80 cu. ft.	90-7200	6,24,29,36
from combined sewers	---	---	---	10 - 80 cu. ft.	---	6,24,29,36
from separate sewers	---	---	---	1 - 18 cu. ft.	---	6,24,29,36
from separate sewers	50	20-40	---	1 - 12 cu. ft. (avg. 4)	---	36
washed	---	10	---	---	---	29
SKIMMED OIL & GREASE	40-60	80-100	Semi-liquid	8 - 67 cu. ft.	260-2200(typ. domestic to industrial wastewaters)	29
SKIMMINGS-SCUM-FLOATING FIBROUS TRASH	60-90	90-95	---	0.1 - 7 cu. ft.	2 - 170	184
ORGANIC SLUDGES (from activated sludge treatment plants)						
Raw Primary	95	---	Liquid	---	---	29
Raw Secondary (waste activated)	97-98	---	Liquid	---	---	29
Mixed Primary & Secondary						
Raw	96(95-98)	40-80	Liquid	321 - 2410 cu. ft. (2390 - 17,900 gal.)	1000-3000	29
Concentrated	94(93-96)	40-80	Liquid	229 - 1200 cu. ft. (1700 - 8940 gal.)	1000-3000	29
Digested	95(94-97)	40-60	Liquid	160 - 800 cu. ft. (1200 - 5980 gal.)	600-1500	29
Filtered, Centrifuged or Heat Treated	40-75	40-80	Gelatinous	---	600-1500	29
Centrifuged Sludge	75-80	---	Gelatinous	---	---	29,135
Vacuum filtered sludge	70-75	---	Gelatinous	---	---	29,135
Air Dried Sludge	50-60	---	Gelatinous	---	---	29,135
Spray Dried Sludge	20-30	---	Granular	---	---	29,135
Kiln Dried Sludge	10-20	---	Granular	---	---	29,135
LIME SLUDGES (from tertiary Phosphorous removal)						
Partially Thickened Tank Withdrawn Sludges	92(90-95)	10-20	Liquid	800 - 4000 cu. ft.	5000-13,000	29
Concentrated (filtered or centrifuged)	50-70	10-15	Semi-liquid	---	5000-13,000	29
Fresh Sludges	95-99	---	Liquid	15,000-45,000 gallons	4000-7000	195
Thickened Sludges	80-92	---	Semi-liquid to Liquid	---	4000-7000	195

C. VOLUME REDUCTION

C. VOLUME REDUCTION

1 - General

Sludge and other wastewater residual solids must be processed to suit the method of final disposal, the method of transportation and local environmental conditions. Such processing may consist of thickening, anaerobic (or aerobic) digestion, air-drying on sand beds, dewatering by centrifuges or vacuum filters, incineration (depending on the state of the sludge, raw or digested), the location and method of ultimate disposal adopted and the method of transportation utilized. 1/

If the sludge is to be incinerated, it may first be dewatered in the raw state on vacuum filters or by centrifuge. Ultimate disposal may be accomplished by reuse of the ash as a conditioning chemical, asphalt filler or stabilizing material, or the ash may be disposed of in a landfill or used for road construction.

For disposal on land the sludge may be in any physical condition -- fluid, gelatinous (thixotropic), or granular (solid) -- convenient for handling, transportation and deposition. Therefore, the most economic method of transportation will determine to a great extent the pretreatment and the physical condition of the sludge to be handled.

Sludge utilized for land disposal may be in a semi-solid or solid state and can be transported by open trucks or railroad cars to the point of disposal. In certain areas barges can play a role in facilitating the transfer of sludges to or nearer the points of ultimate land disposal. Pretreatment could consist of any of the dewatering methods listed above. Simple loading and unloading methods may then be used.

Disposal of sludge on land may also be accomplished with the sludge in a fluid state. In this case tank trucks, tank cars, tank barges or pipelines can be employed. Pretreatment for handling as a fluid may consist only of concentration or dilution to the desired solids content for optimal handling or it may include further preparation for pipeline transport.

1/ General References for this Technical Appendix III Chapter include: 6, 9, 24, 25, 29 - 37, 39-41, 45, 47, 64-81, 88, 89, 93, 94, 97, 101, 102, 103, 104, 119, 121, 122, 125, 127, 136.

When transporting sludge in pipelines, the fluid (or slurry) may be diluted to facilitate fluid flow. When applied to land as a soil conditioner, the liquid content of the sludge has both a fertilizer value and an irrigation benefit.

Volume reduction of solids can be accomplished by a number of methods. These methods have been developed to handle a wide variety of waste materials. Some methods are suitable for many different materials while others are only suitable for selected materials. A large number of present volume reduction methods and equipment are proprietary and it is expected that this situation will continue. It should be noted that solids handling is one of the major problems of wastewater treatment and that volume reduction is a major factor of the solids handling problem.

Volume reduction is principally a process of dewatering which reduces sludge moisture content and, hence, bulk volume. It also destroys the colloidal structure of the sludge in some cases. Some variation in the solids-to-water ratio (concentration) is obtainable in the various volume reduction methods although the general practice is to operate each particular installation to obtain the maximum concentration of solids and therefore the maximum volume reduction. Thus, concentration limitations are primarily dependent on the physical constraints of the process employed. The selection of the specific process used for volume reduction is usually based on criteria including concentration capability, type of solid material to be handled and cost.

Volume reduction can be accomplished by relatively cheap and simple methods such as air drying in open beds or more complex and expensive methods such as filtration (vacuum and pressure), artificial heat drying and complete incineration. Generally, the cost of volume reduction increases as more rapid concentration processes are utilized. The unit costs for each method of sludge concentration vary considerably and are affected by such factors as the type of material being handled, the type of pretreatment or conditioning utilized (if any), local chemical, power, fuel and labor costs and percent of maximum concentration required.

From the foregoing discussion, it becomes clear that volume reduction processes involved two principal subgroupings: (1) the physical solids concentration and water removal processes of dewatering, thickening, filtration, flotation, centrifuging and drying, and (2) the chemical compound changing processes of heat treatment, oxidation, incineration and digestion. Some clarification of some terminology is called for at this point, particularly in view of variations in usage to be found in the literature.

Oxidation or chemical oxidation are terms which refer to processes where organic compounds are broken down, "decomposed," "stabilized," "degraded" or "converted" into simpler compounds with lower molecular specific energies. They are exothermic, i.e., accompanied by the release of energy in some form. These processes involve the loss of electrons or hydrogen atoms from the molecules being oxidized and are frequently accompanied by molecular combination with molecules of oxygen, the latter providing some basis for the distinction between the term chemical oxidation in its broadest sense and simple oxidation (with molecular oxygen, atmospheric, gaseous or chemically combined) in a slightly more restricted sense. Chemical oxidation thus constitutes one broad class of chemical "conversion" processes where compounds (or chemical "species") are transformed into new compounds (or chemical "species"). The idealized end products of complete chemical oxidation are carbon dioxide, water, other gaseous end products and an inert solid residue or ash which contains no organic matter. This latter provides the basis for the concept of complete "stabilization" or nonputrescibility, or non-susceptibility to biological decomposition oxidation processes, particularly the anaerobic (Refs. 6-25).

Incineration is a specific type of oxidation process; it consists of high temperature combustion or burning, conventionally between 1400-2000°F, whose objective is the substantial "destruction" or "conversion" or "stabilization" of combustible waste materials together with substantial reductions in their original volumes. Since the degree of volume reduction is about twenty times, incineration is considered an important volume reduction process. It is discussed in depth in Appendix Chapter III-C. Combustion in general refers to oxidation processes involving chemical combination with atmospheric oxygen and the production of heat and light energy, the production of heat, light and/or power often being its principal objective. Ordinary combustion or burning takes place between 500 and 1500°F. Unconventional high temperature incineration takes place above 2000°F.

Biochemical or biological oxidation is the oxidation resulting from the activities of various kinds of life processes initiated through the mechanism or agency of enzymes or organic catalysts. Respiration is a term which refers to the biochemical utilization or oxygen in some form by biological organisms or processes. Fermentation is a term used by many to refer to biochemical oxidation through the agency or microorganisms specifically.

Aerobic oxidation (or decomposition, degradation, digestion, stabilization, respiration or fermentation) is biochemical oxidation produced by direct or gaseous respiration of organisms or other form of biological activity in an excess of atmospheric oxygen.

Anaerobic oxidation (or decomposition, degradation, digestion, stabilization, respiration or fermentation) is biochemical oxidation produced by non-gaseous respiration of organisms in the absence of atmospheric oxygen. One principal type involves intermolecular respiration where the oxidation of one organic compound takes place with the simultaneous reduction (gain of electrons or hydrogen atoms) of another organic compound. The other principal type is intramolecular respiration which involves the splitting of a molecule with one part being oxidized at the expense of and the reduction of the other. Fermentation in its restricted usage or glycolysis is the intramolecular form of anaerobic biochemical oxidation where molecular splitting occurs with the side chains of the molecule being oxidized at the expense of the main body of the molecule. Alcoholic fermentation is an example of this. Putrefaction is another form of intramolecular anaerobic oxidation where molecular splitting takes the form of hydrolytic cleavage of the main body of the original molecule with subsequent loss of hydrogen (dehydrogenation). More generally the term refers to the anaerobic decomposition of proteinaceous matter into foul-smelling incompletely oxidized end products. Putrescence and putrescibility are associated terms. The principal gaseous end products of anaerobic oxidation are carbon dioxide, methane, hydrogen sulphide (the source of rotten egg odors), and in the case of putrefaction the foul-smelling mercaptans, the latter involving the SH radical instead of the hydroxide or OH radical.

Digestion is a term referring to the use of aerobic or anaerobic biochemical oxidation processes to treat, decompose and stabilize organic waste materials. The term draws attention to the principal agency involved, micro-organisms, which "digest" the waste organics as their food and accomplish the decomposition desired. In this report, the term will usually refer to anaerobic sludge digestion, the anaerobic microbiological activity usually confined to relatively large enclosed storage tanks. Digestion is discussed in some depth in Section III-C-6.

Composting is another related term and is discussed in some depth in Section III-F-3. Composting is the man-managed microbiological decomposition, digestion, degradation or stabilization of relatively dry organic materials (40 to 70 percent moisture) by aerobic or combined aerobic-anaerobic (facultative) biochemical oxidation processes. The end products are carbon dioxide, water, mineralized organics and humus. Humus is a substantially stabilized organic material with properties very much like those of the organic fraction of topsoil. Composting is very similar or seemingly identical to other microbiological oxidation processes, particularly to those which take place in dilute slurries (i.e., sludge digestion) or in suspended or dissolved organic materials

involved in various wastewater treatment processes (i.e., activated sludge, trickling filtration) and most particularly to those which take place naturally in soils. The older and most ancient combined aerobic and facultative mesophilic composting (60-110°F) encompasses far slower processes and may utilize fungi not present in aerobic composting. Modern composting is a much more rapid and a thermophilic (110-185°F) process which utilizes bacteria (schizomycetes), actinomycetes and fungi proper (mostly ascomycetes, basidiomycetes and fungi imperfecti). It produces considerable quantities of heat. The end products of composting have quite different physical characteristics from those of other microbiological processes, particularly with respect to the humus-like material very definitely associated with composting. Trickling filter "humus" is a similar end product.

2 - Thickening and Dewatering

a. Gravity Thickening

Gravity thickening is basically a physical settling process and is relatively slow. Settling or sedimentation in general is a unit operation used to separate waterborne wastes from wastewaters by the force of gravity. With the flow velocity of the process stream sufficiently reduced, solid materials with a specific gravity greater than water (i.e., weighing more than water per unit of volume) will sink to the bottom of the stilling basin, settling or sedimentation tanks, or clarifiers. The central purpose of sedimentation in wastewater treatment is the removal of certain solids fractions from the process stream in order to facilitate the subsequent separate treatment and/or disposal of the wastewater and the separated solids and sludges. Settling can also be used for thickening already separated sludges where the sludge solids constitute under 5 percent of the total mass. Thickening thus consists of follow-up settling where the solids are further concentrated into a portion of the wastewater mass initially separated from the main process stream with the sludge solids.

Gravity methods of sludge volume reduction are utilized in many solids handling systems and are employed in such operations as digestion, elutriation, heat treatment and wet oxidation. Gravity thickening is commonly used to assist the separation of solids from the liquid flow in treatment facilities employing separate solids handling. This procedure produces sludges which require further processing.

The gravity thickening process involves the concentration of dilute sludge in tanks specially designed for thickening purposes. The

thickening tank is equipped with slowly moving vertical paddles. Sludge is pumped continuously from the settling tanks to the thickener at low overflow rates. This low overflow rate is essential to allow concentration of sludge solids at the bottom of the tank. Gravity thickening can also be accomplished by storage and decantation. Here it is the more clarified liquor which is "removed" rather than the thickened sludge mass.

Gravity thickening can generally double the sludge concentrations, although depending on the characteristics of the sludge, higher concentration ratios can be obtained. Since gravity thickening is time-dependent, the freshness of an organic sludge is important in maintaining high concentration efficiencies. As sludge age increases, the probability of septicity (and resulting gas formation and rising of the sludge) increases, thereby defeating the purpose of gravity settling and concentration. Because of this effect, sludge age can be the limiting factor in gravity sludge concentration. Gravity thickening can be attained in simple storage tanks by décanting the supernatent as the sludge solids settle. Organic sludges left untreated for more than 8 to 10 hours will usually go septic unless aeration is employed, this aeration disrupting the quiescent settling process. Many improvements have been made in the mechanical equipment and processes used to aid gravity concentration. Recently, use has been made of chemical coagulants as supplemental aids to improve coagulation and gravity concentration.

Final solids concentrations from gravity thickeners generally are less than 10 percent, and are limited by the practical considerations of preventing septicity and maintaining adequate sludge pumping and handling characteristics. Sludges generally require additional dewatering or volume reduction before they become suitable for handling as solids. Gravity thickeners are extensively utilized before final dewatering since the process is relatively simple, cheap and compact. Volume reduction by gravity thickening can generally be used for all solids except oil and grease, the latter tending to float rather than settle.

The following table presents the tickening-by-gravity which can be anticipated for different organic sludge types.

Table III-C-1

GRAVITY THICKENERS: UNIT PROCESS PERFORMANCE

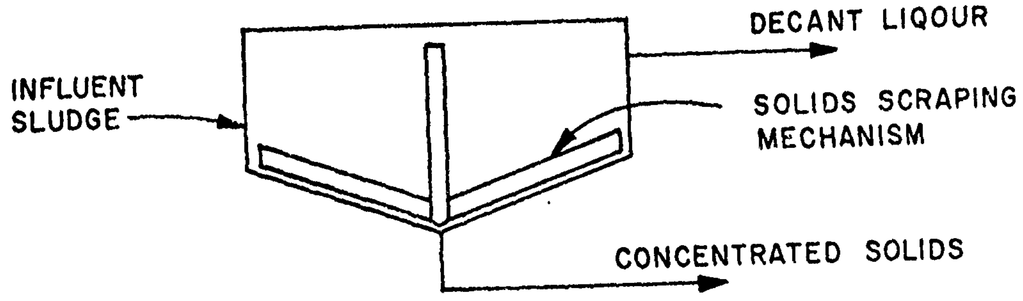
Description	Loading ($lbs/ft^2/day$)	Susp. Solids Influent %	Susp. Solids Thickened %
Activated Sludge	----	----	6.0
Activated Sludge	----	0.8	3.5
Primary Sludge	24.2	1.8	9.0
Primary & Secondary	17.9	0.2	4.5
Trickling Filter	8-10	----	7-9
TF & Activated	10-12	----	7-9

(Ref. 119)

A special application of gravity separation is the elutriation process. This involves washing the sludge and decanting off the water. It has been used in both batch and continuous operations. The process is useful for both interstage in digestion or on final digested sludge for concentration of solids. The elutriation process has also been used to wash toxic materials out of sludge prior to digestion.

Elutriation has been used extensively to reduce the amount of chemicals required for satisfactory dewatering of digested sludge, i.e., required for chemical sludge conditioning. The basic purpose of elutriation is to reduce the sludge alkalinity which increases during the digestion process and which reacts with the sludge conditioning chemicals. The elutriation process removes much of the alkalinity by washing the sludge with plant effluent or fresh water and thereby reduces significantly the amount of chemicals required to enhance dewatering. Of necessity, therefore, elutriation is employed prior to chemical sludge conditioning. Elutriation has found its greatest use in large plants where the total chemical requirements would be very large if the alkalinity were not reduced. More recently, the introduction of polymers has reduced the need for elutriation because polymers are not affected by alkalinity. Alkalinity is the capacity of ions for neutralizing acids, i.e., the possession of chemical base-like properties, and is usually due to the presence of bicarbonate (HCO_3^{-1}) and carbonate (CO_3^{-2}) ions. High alkalinity is associated with high pH values.

A typical gravity thickener is illustrated in Figure III-C-1. Cost curves have been developed and are presented in Figure III-C-2 (Ref. 29).



GRAVITY THICKENER

Figure III-C-1

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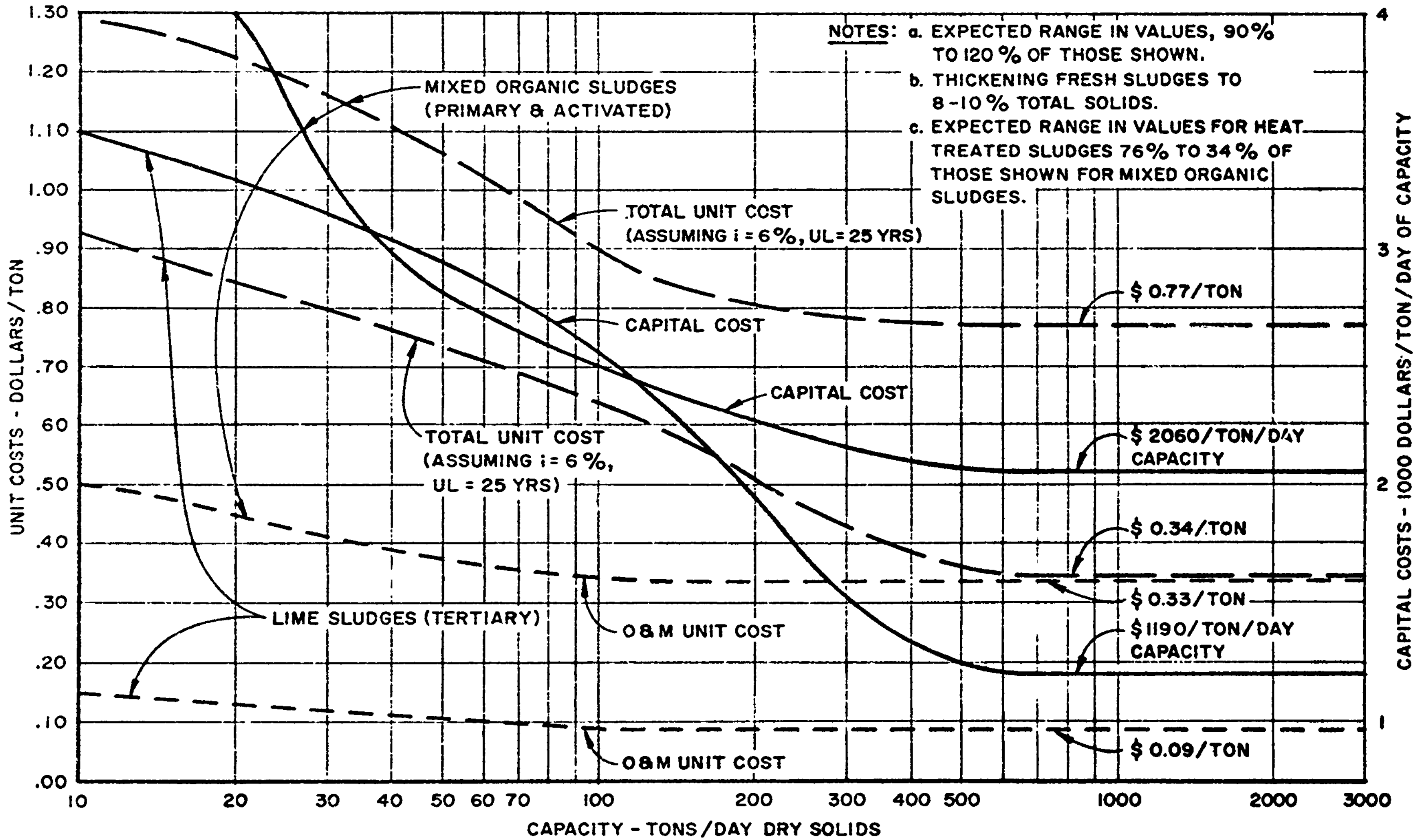


(from Ref. 29)

GRAVITY THICKENER COST CURVES

(JANUARY 1972 ADJUSTED)

Figure III - C - 2

b. Vacuum Filtration

Filtration, in general, is a term referring to a process for removing suspended and colliodal matter from water, wastewater or other process streams by means of flowing or trickling the streams through or over a porous or open-textured medium. This results in the suspended or colloidal matter being left behind in the pores or openings or on the surfaces of the medium and from which this matter must be subsequently removed. The operation combines several more specific processes:

1) Straining. A form of screening whereby particles larger than pore openings are caught in these openings, this leading to the subsequent catching of particles larger than the openings in the mat formed from "caught" matter. The mat is rendered sticky or slimy and hence more effective as a straining mechanism by action of zoogleal micro-organisms.

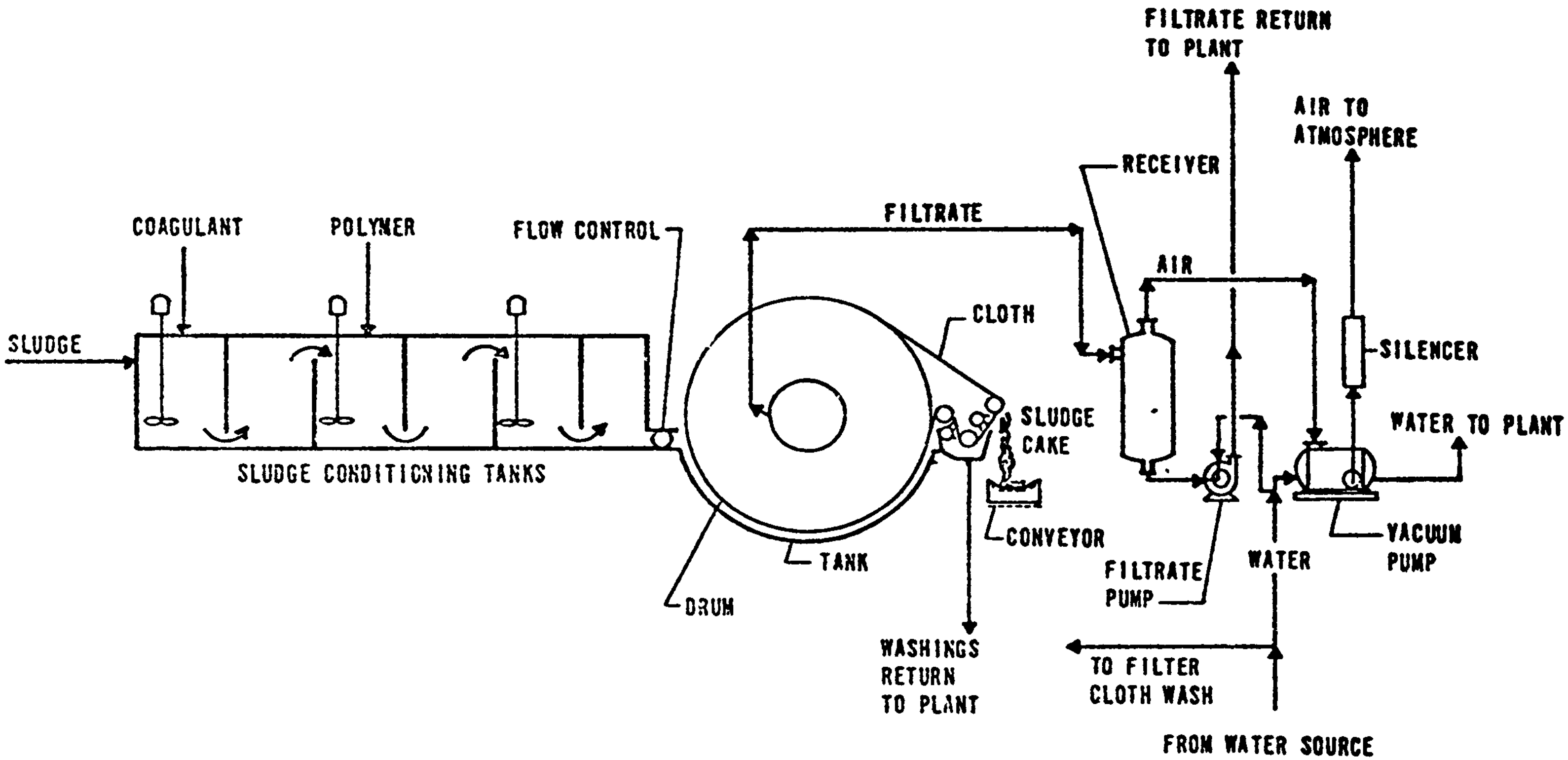
2) Sedimentation. The settling of particles smaller than pore openings within the medium's void spaces which thus act as stilling basins or sedimentation "tanks."

3) Flocculation by means of increased interfacial contact opportunity. The agglomeration or the lumping of suspended or colloidal particles with one another by means of greater contact opportunity, this latter enhanced by the constricted flow through the pores and through the openings in the mat and between flocs and surfaces of the medium.

4) Microbiological activity. The feeding of microbiota on filtered suspended or colloidal matter which produces a slimy or sticky zoogleal mat which enhances the straining, sedimentation and flocculating mechanisms; also their ingesting of dissolved organic matter thus effecting their removal. Vacuum filtration is a form of mechanical filtration utilizing suction force to pull the process stream through the pores of the medium and the mat.

Vacuum filtration has been the mainstay of wastewater sludge dewatering for many years, particularly at larger installations. A typical vacuum filtration operations sequence is illustrated in Figure III-C-3. Newer processes are supplementing and, in some cases, replacing vacuum filtration. Continuous vacuum filters used for sludge dewatering consist of large rotating drums covered with filter media which holds the solid material on the outside surface while pulling the liquid through the filter fabric under vacuum. Drum vacuum filtration is a continuous process whereby sludge is fed to one side of the filter drum, the liquid being drawn off by vacuum and, as the drum rotates, the dewatered sludge is scraped off and the drum is readied for additional wet sludge. Capacity of vacuum filters depends on a number of variables including feed sludge characteristics and water content, desired water content in the filter cake, type of filter equipment and filter fabric material, sludge conditioning, and speed of drum rotation. The larger filters currently being manufactured can dewater from 20 to 50 tons of dry solids per 24 hours, although under optimum conditions with no mechanical problems, continuous operation, correct chemical dosages, well conditioned sludge and knowledgeable operation, dewatering of up to 100 tons per 24 hours is theoretically possible. This theoretical capacity is not used for design purposes because sludges cannot be maintained at optimum conditions and because the filters require maintenance.

Most vacuum filter installations employ sludge conditioning prior to dewatering on the filters. This conditioning can include the addition of chemicals, such as ferric chloride, lime or polymers, elutriation, and more recently, wet oxidation or heat treatment. Sludge conditioning allows more efficient dewatering and greater capacity per square foot of filter area once the sludge is actually placed on the filter. At most vacuum filter installations, it has been found that without sludge conditioning dewatering becomes very difficult, resulting in overloading of the filter facilities and high water content in the filter cake. Vacuum filtration has generally been used for organic sludges although certain other sludges, such as lime sludges, can also be successfully dewatered. The factors governing the type of sludge which can be successfully dewatered by vacuum filtration are basically whether the material will pass through the pipes and conduits leading to the filter and whether the material will pass through the pores of the filter media. The proper application of vacuum filters is to materials which bridge across the filter media until they are scraped off. Cloth is the usual filter media, although for undigested sludge, wire spring or metal fabric media are more effective.



(from Fig. 12-1, Ref. 30)

TYPICAL VACUUM FILTER FLOW DIAGRAM

Figure III-C-3

A considerable amount of auxiliary equipment is necessary for vacuum filters, as is illustrated in Figure III-C-3. Nevertheless, the overall costs are comparable with centrifuges. Cost curves have been developed (Ref. 29) and are presented in Figure III-C-4. For larger installations, slightly more favorable costs can often be obtained with vacuum filtration. Vacuum filters can consistently produce a filter cake with approximately 20 to 25 percent solids. With close control of both the wastewater treatment and solids handling processes, concentrations of solids up to 35 percent can be obtained.

Continuous leaf and horizontal belt filters have been used for vacuum filtration of sewage solids but their cost and space requirements do not make them economical except for special conditions.

The sludge, depending on type, is applied at varying rates. Usually from 2.5 to 5 pounds of dry solids per hour are filtered per square foot of filter media (Ref. 127).

Vacuum filtration can be expected to achieve the results presented in the following table:

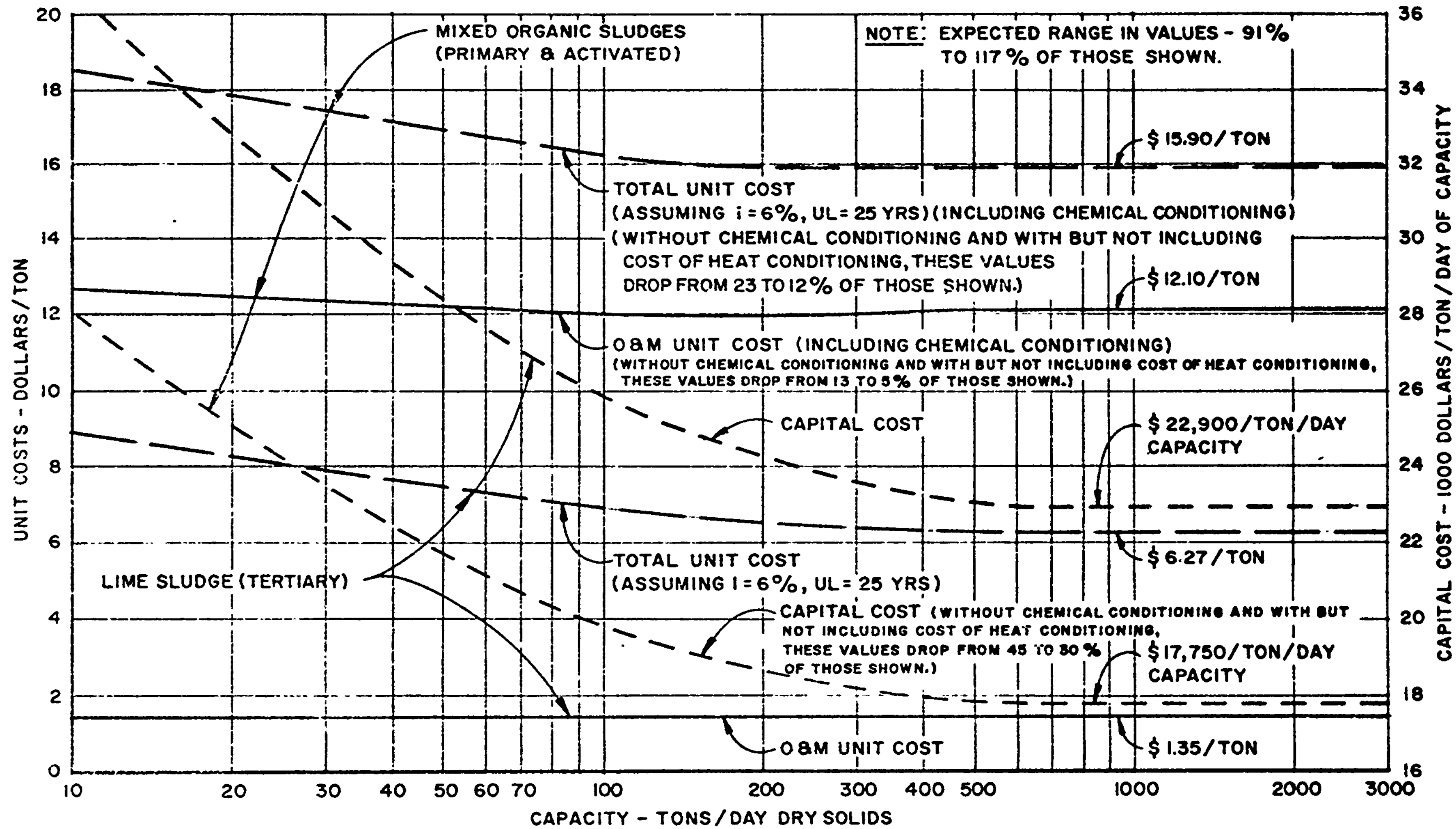
Table III-C-2
VACUUM FILTRATION UNIT PROCESS PERFORMANCE

Description	Susp. Solids Influent (%)	Percent Solids in Filter Cake	Yield ($lbs/ft^2/hr$)
Raw Primary	----	18.2	6.3
Activated	----	25.0	3.7
Trickling Filter	----	20.2	9.9
Digested Primary	0.2 - 1.5	26-30	7.0
Digested Primary and Activated	0.5 - 2.0	24-30	6.0

(Ref. 119)

c. Pressure Filtration

Pressure filtration is not widely used in the United States due principally to its inherent non-continuous operation and accompanying high labor costs. It has been widely used in England and Europe for over thirty years where labor costs are lower, and, because of the cost of operation, a higher water content sludge has usually been more



(from Ref. 29)

VACUUM FILTRATION COST CURVES

(JANUARY 1972 ADJUSTED)

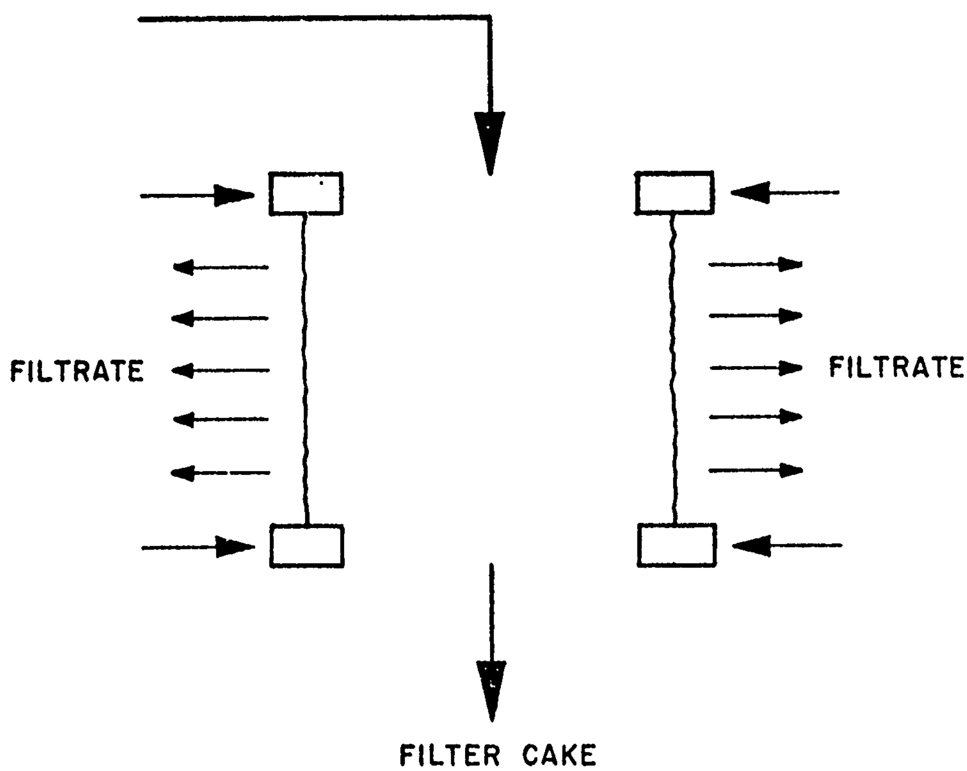
Figure III - C - 4

acceptable. On some sludges, pressure filtration can produce solids concentrations up to 50 percent. Pressure filtration equipment presently available essentially squeezes water out of sludges. This takes place between two plates covered with filter material which are pressed together (see Figure III-C-5). The filter material can be varied as necessary for the material being dewatered. Generally, greater concentration of the solids can occur with pressure filtration than with other dewatering processes except heat drying or incineration.

d. Centrifugation

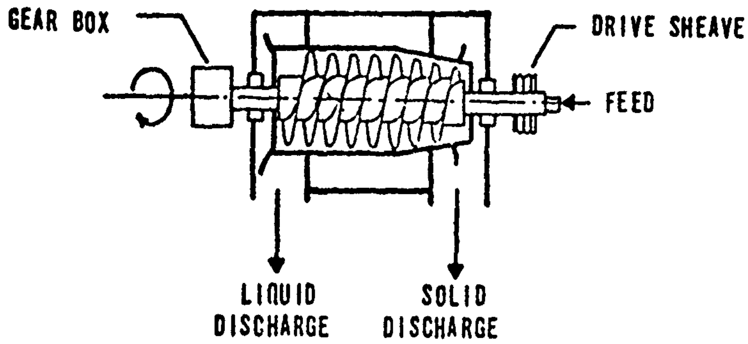
Centrifugation employs centripetal force to effect the separation of sludge solids from a major portion of the influent water mass. Centrifuges have been used for sludge dewatering for a number of years with limited success due to the characteristics of sewage solids and the inapplicability of standard industrial process centrifuges. The major problem has been the disintegration of sewage sludges which produced centrates of high BOD and introduced severe problems in further treatment. Recently, centrifuges have been developed specifically for concentrations of sewage sludges and these, together with polymer chemicals, have made the process practical. A number of different types of centrifuges are available; however, most sludge processing units are continuous flow solid bowl units (see Figure III-C-6 for illustrations of the three major types). This bowl type of centrifuge usually operates at speeds up to 2500 RPM and can apply from about 1000 to 5000 times the force of gravity to the material passing through the machine. The amount of dewatering or concentration of solids depends on operating conditions and end product needs. Material up to approximately 30 percent solids can be obtained; however, to avoid poor quality centrate,centrifuges are generally operated to provide a discharge of about 15 percent solids. Chemicals are quite often used to improve centrifugation although the amount of chemicals normally used is nominal. The chemicals are usually one or more polymers selected after evaluating the specific sludge being dewatered. Power and maintenance are the major costs of operation. Since a centrifuge is a fairly complex piece of equipment which operates at high speeds, considerable wear occurs. Wear will vary depending on the amount of abrasive solids in the feed material. Therefore it is usually preferable to exclude grit from centrifuge feed.

Centrifuges are generally satisfactory dewatering devices for organic, lime, toxic and regenerative solids. Material subjected to centrifuging must be small enough to pass through the restricted openings within the equipment. Screenings could be dewatered by centrifuging if completely ground first. Usual practice, dictated by economics, is to drain screenings sufficiently prior to disposal.

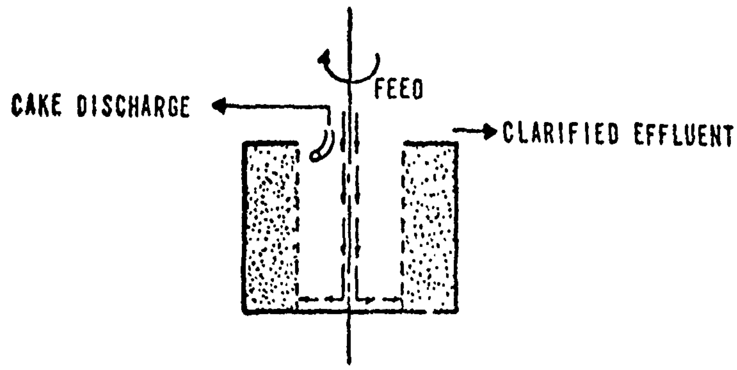


PRESSURE FILTRATION

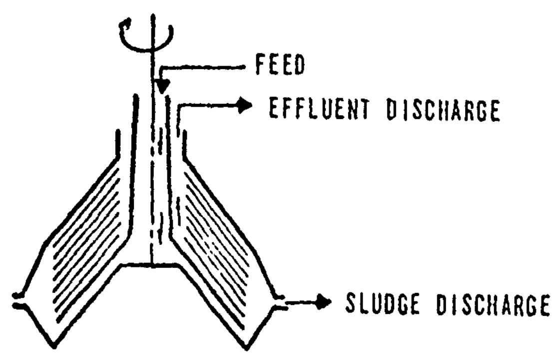
Figure III - C - 5



SOLID BOWL CENTRIFUGE



SOLID BOWL BASKET CENTRIFUGE



DISC TYPE CENTRIFUGE

(from Fig. 12-2, Ref. 30)

VARIOUS CLASSIFICATIONS OF CENTRIFUGES

Figure III - C - 6

Oils and greases can often clog openings or adhere to metal parts and therefore solid bowl centrifuges are rarely used for oil and grease dewatering. Although batch centrifuges can be used, operating costs are very high. Special self-cleaning centrifuges can be successfully used for oil and grease separation at about twice the initial cost of solid bowl units. Grit should not be centrifuged due to the severe effect on machinery life.

The most effective centrifuges for dewatering waste sludges are horizontal, cylindrical-conical and solid bowl machines. Basket centrifuges dewater sludges effectively but liquid clarification is poor. Disc-type machines do a good job of clarification but their dewatering capacities fall in a lower range than solid bowl units (Ref. 154).

For a typical solid bowl unit, the operation is as follows. The sludge is fed through a stationary feed tube along the centerline of the bowl through the hub of the screen conveyor. The screen conveyor is mounted inside the conical bowl which rotates at a slightly slower speed. Sludge leaves the end of the feed tube, is accelerated, passes through ports in the conveyor shaft, and is distributed to the periphery of the bowl. Solids settle through the liquid pool, are compacted by centrifugal force against the walls of the bowl, and are conveyed by the screen conveyor to the drying area of the bowl. Table III-C-3 presents centrifuge performance data for different organic sludge types.

Table III-C-3
CENTRIFUGE PERFORMANCE

Description	Influent SS (%)	Cake Solids (%)
Digested Sludges	3-5	25-39
Digested - Primary Sludges	4.0	20-32
Digested Primary and Activated Sludges	3-5	20-26

(Ref. 119)

The overall costs of centrifuge operations on mixed organic sludges are approximately equal to those for vacuum filtration operations, this observation being borne out both from the literature (Ref. 154), from liaison with manufacturing companies, and from a comparison of Figure III-C-7 (Ref. 29) with Figure III-C-4. With lime sludges, vacuum filtration has significantly lower costs.

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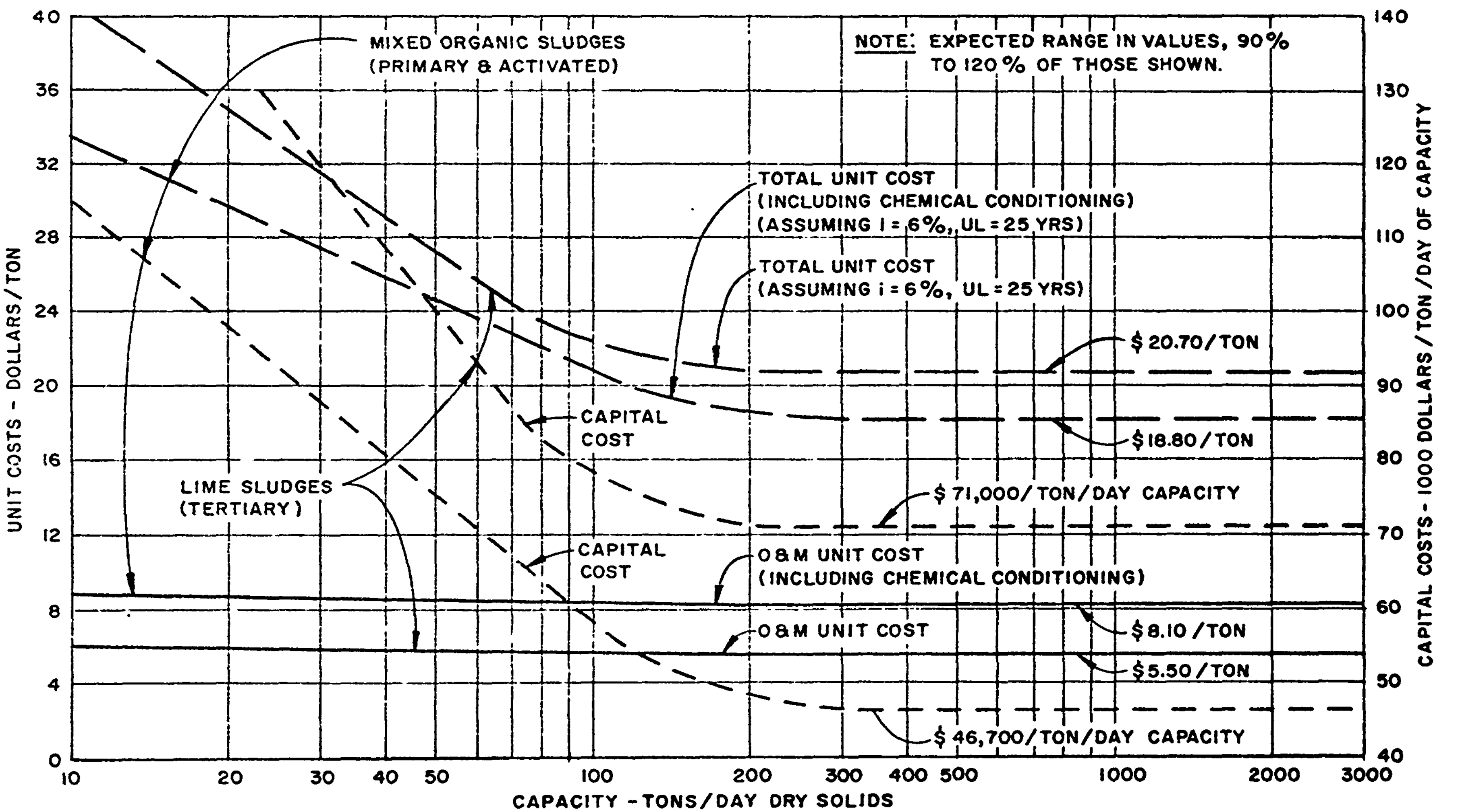


(from Ref. 29)

CENTRIFUGE COST CURVES

(JANUARY 1972 ADJUSTED)

Figure III-C-7

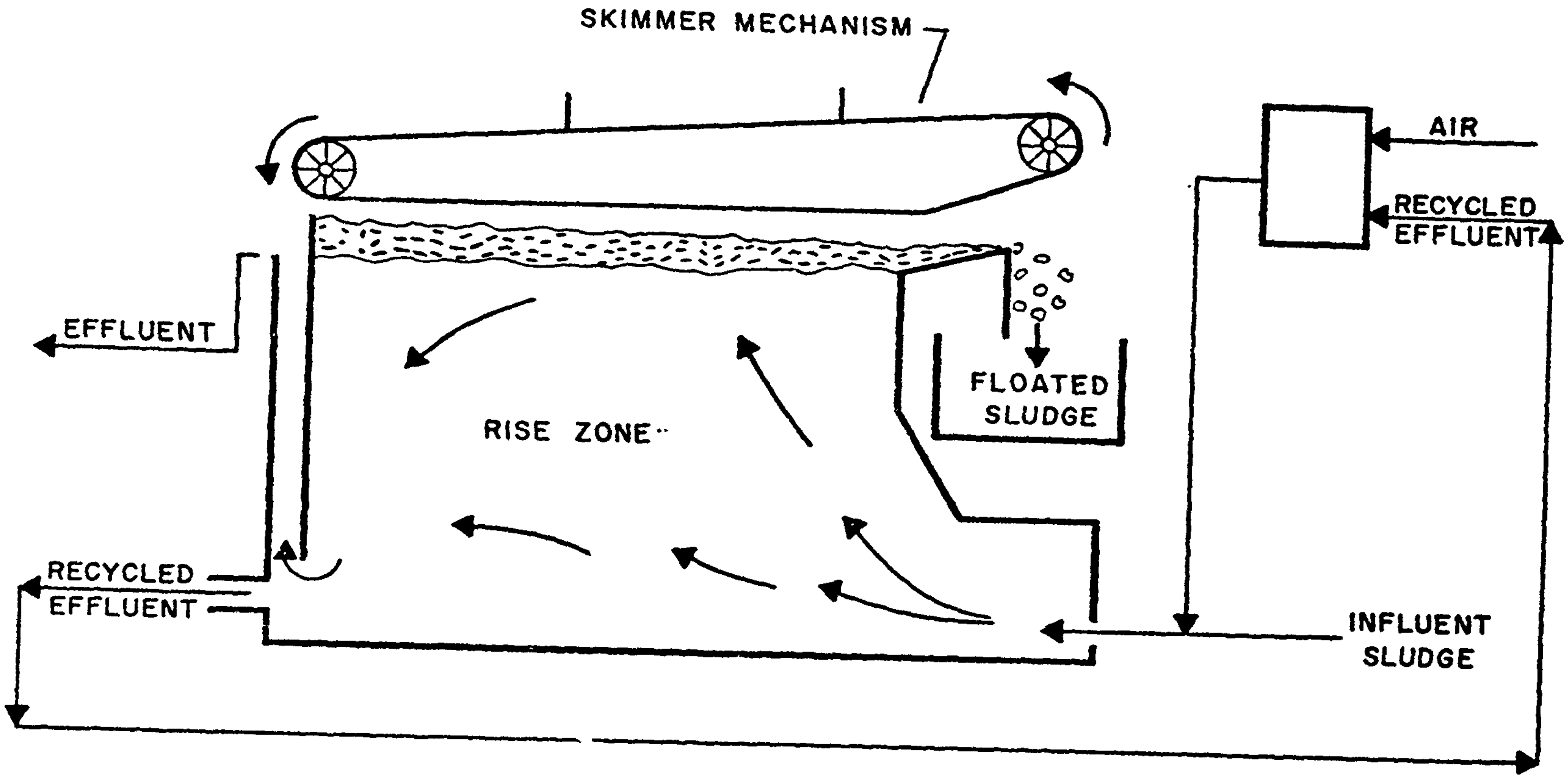
e. Air Flotation

Air flotation is employed for the removal of suspended solids from wastes and for the separation and concentration of biological flocculent sludges. This concentration process causes sludge material to float to the surface where they can then be removed. Air flotation is generally applicable when sludges have specific gravities of about 1.05 or less. It is utilized extensively for concentrating oil and grease sludges and light activated sludge process secondary sludges. Air flotation can also be used for certain screenings, toxic and regenerative solids when the specific gravities are close to 1.0. A typical air flotation unit is illustrated in Figure III-C-8.

Air flotation is a relatively simple and compact process when properly applied. It operates on the basic principle of dissolving air under pressure in liquid under pressure, then allowing a reduction in pressure which causes the dissolved air to form small bubbles which attach to the sludge particles. The most important factor in air flotation is sludge density. If the sludge is nearly the same density as the liquid, the sludge will rise to the surface where it can be removed by skimming. The cost of concentrating by air flotation is usually more than for gravity settling since power and auxiliary equipment are required to pressurize the air and water. Cost curves have been developed and are presented in Figure III-C-9 (Ref. 29).

The air flotation process takes advantage of the fact that light sludges would go septic in a gravity thickener prior to reaching desired concentration while in air flotation they rise and concentrate more rapidly thereby allowing quick removal. Air flotation also takes advantage of the light densities inherent with activated sludges. It is not used for concentrating grit, lime sludges or other heavy sludges. Air is sometimes used in grit chambers to assist in separating organic and inorganic materials, but this should not be considered an air flotation process.

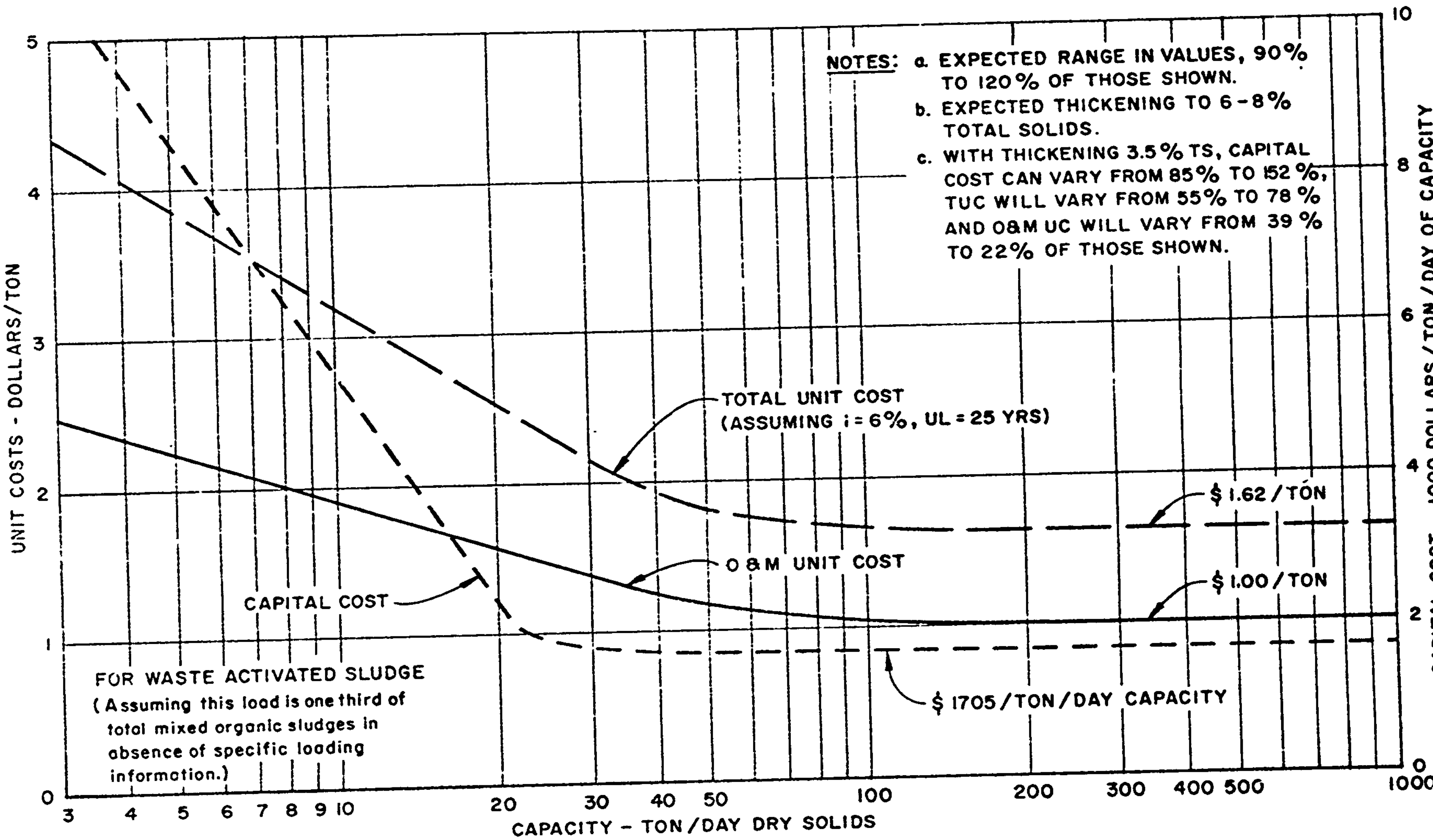
A modification of the air flotation process is vacuum flotation in which the sludge is pumped into a vacuum tank and the release of dissolved gases causes the sludge to rise to the surface where it is skimmed off. The cost of vacuum tanks, especially in larger sizes, and maintenance problems have discourage wide application of this process.



(adapted from Fig. 10-1, Ref. 30)

SCHEMATIC OF AN AIR FLOTATION UNIT

Figure III-C-8



(from Ref. 29)

FLOTATOR COST CURVES

(JANUARY 1972 ADJUSTED)

Figure III-C-9

The following table presents air flotation thickening performance data for various organic sludges.

Table III-C-4
AIR FLOTATION THICKENING PERFORMANCE

Organic Sludge Type	Influent SS (%)	Float Solids (%)
Activated	0.8	6.5
Activated and Primary	0.6	8.6
Activated and Primary	1.9	6.4
Activated and Primary	2.3	5.9

(Ref. 119)

3 - Drying and Heat Treatment

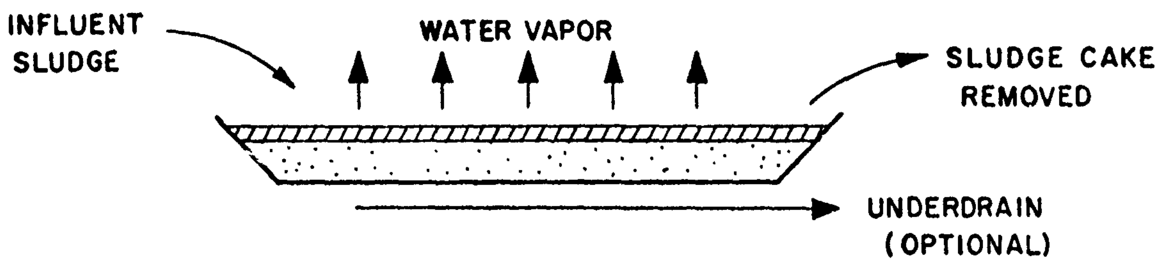
Drying is a unit operation designed to separate significant to major portions of the water in wet sludges from the sludges solids by means of evaporating the water fraction. Drying is thus one distinctive subgrouping of sludge volume reduction.

Heat treatment methods, in contrast, are a form of sludge conditioning. They are designed to stabilize the organic portion of the sludge solids prior to dewatering in order to facilitate this dewatering. Heat treatment is finding increased application due to several inherent advantages. Most of the heat treatment processes involve raising the temperature and pressure of the sludge, but not to the degrees practiced in wet oxidation. The heat treatment methods in use are proprietary.

Heat treated sludge can be dewatered without digestion and without the use of chemicals. Dewatering capabilities are improved somewhat with vacuum filter cake solids concentrations up to about 45 percent being possible. Although the initial capital costs are relatively high, and power and heat are required for operation, it appears that heat treatment may be advantageous as a conditioning procedure in sludge volume reduction.

a. Air Drying (Sand Bed Drying)

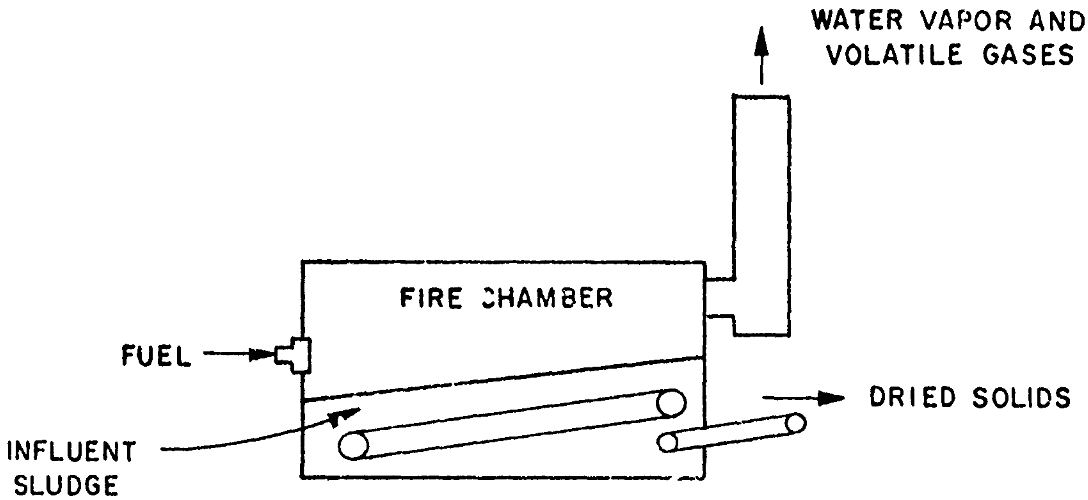
Air drying of wastewater sludges is the simplest and most widely used method of volume reduction. It is illustrated in Figure III-C-10.



SAND BED DRYING

(Air Drying)

Figure III-C-10



HEAT DRYING

Figure III-C-11

It is also the cheapest method where land is readily available and the climatic conditions are suitable. Capital improvements for this method are nominal and generally consist of small dike construction, bottom surface preparation and pipe and valve installation. Cost curves have been developed and are presented in Figure III-C-12 (Ref. 29). Air drying of sludge can be quite innocuous and trouble free if the sludge is stabilized through processes such as digestion or heat treatment prior to spreading. Otherwise the organic matter in the sludge will decompose with accompanying release of odors and will also allow exposure to pathogens and provide breeding areas for flies. Public opposition usually requires that the process occur at a remote location. The residual material can be handled much like regular soil and, if it is originally derived from an organic sludge, it is valuable for soil conditioning and low level fertilizing. Good sand bed dried organic sludge will have a solids content of about 40 percent and a volume about one-half of the original wet sludge. Sludge lagooning is a means of stabilization and concentration but does not usually result in a water content reduction approaching that of bed drying.

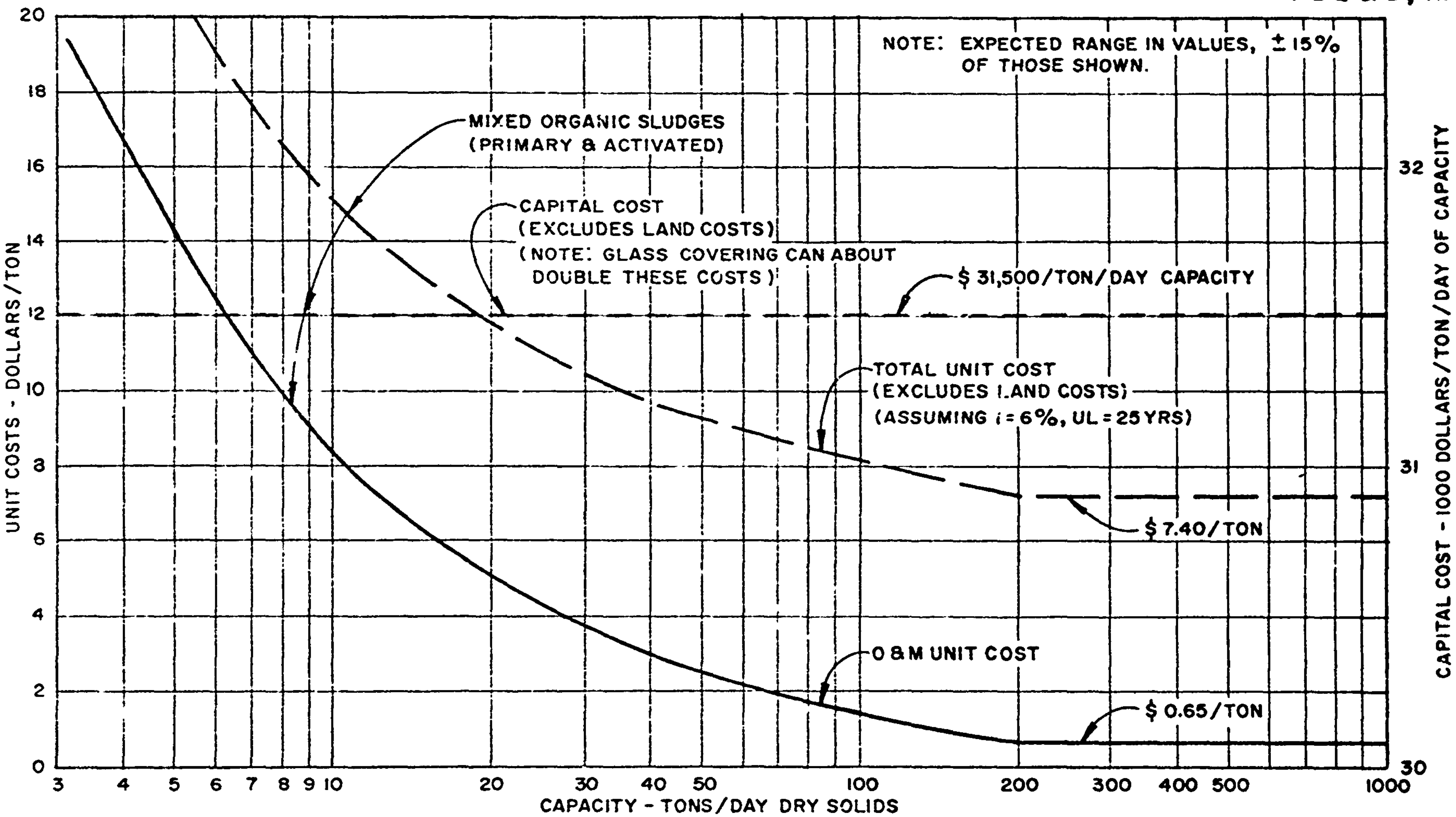
b. Heat Drying

Heat drying is the controlled heating of sludges to the point of driving off water without the combustion of the solid material. This method can be useful when subsequent use of the materials is planned which would preclude combustion. A good example of this is heat drying of digested organic sludges for subsequent fertilizer uses.

Heat drying has not been employed to any great extent in recent years because, except for a few notable cases, there is little demand for dried sludge. Therefore, if a furnace installation is utilized, it is usually as an incinerator for reducing the organic sludge to a resultant ash. Heat drying of stabilized sludges may find more application again in the future if greater emphasis is placed on recycling useful waste products. The encouragement of sludge recycling may require subsidization, as present operations may not be economical. Heat drying for volume reduction purposes can be applied to all types of sludges if proper temperature and oxygen controls are maintained and proper equipment is utilized.

Heat drying units have included the following types: (1) atomizing spray dryers, (2) rotary dryers, (3) multiple-hearth dryers, and (4) flash dryers (the latter discussed in somewhat more detail in Section III-C-3f). A typical heat drying unit is illustrated in Figure III-C-11. A rotary kiln dryer operations sequence is indicated in Figure III-D-10 if the incinerator kiln and its subsequent operations are eliminated from this figure. The cost information on heat drying

PBQ & D, Inc.



(from Ref. 29)

SAND BED AIR DRYING COST CURVES

(JANUARY 1972 ADJUSTED)

Figure III -C-12

is rather sketchy (Ref. 154). It is estimated that current total unit costs would be about $70/ton dry solids average with variations ranging from 80 percent to 110 percent of this value. Operating costs would constitute about two-thirds of the total unit cost.

c. Porteous Process Heat Treatment

In the Porteous process (Ref. 125, 136) the organic sludge (primary or secondary) is pumped from a sedimentation tank or digester to a storage tank as indicated in Figure III-C-13. The sludge is then ground and pumped through a heat exchanger to the reaction vessel. Steam is injected into the reactor under pressure, 180-210 psi, and reaction temperatures are maintained at 350°-390°F.

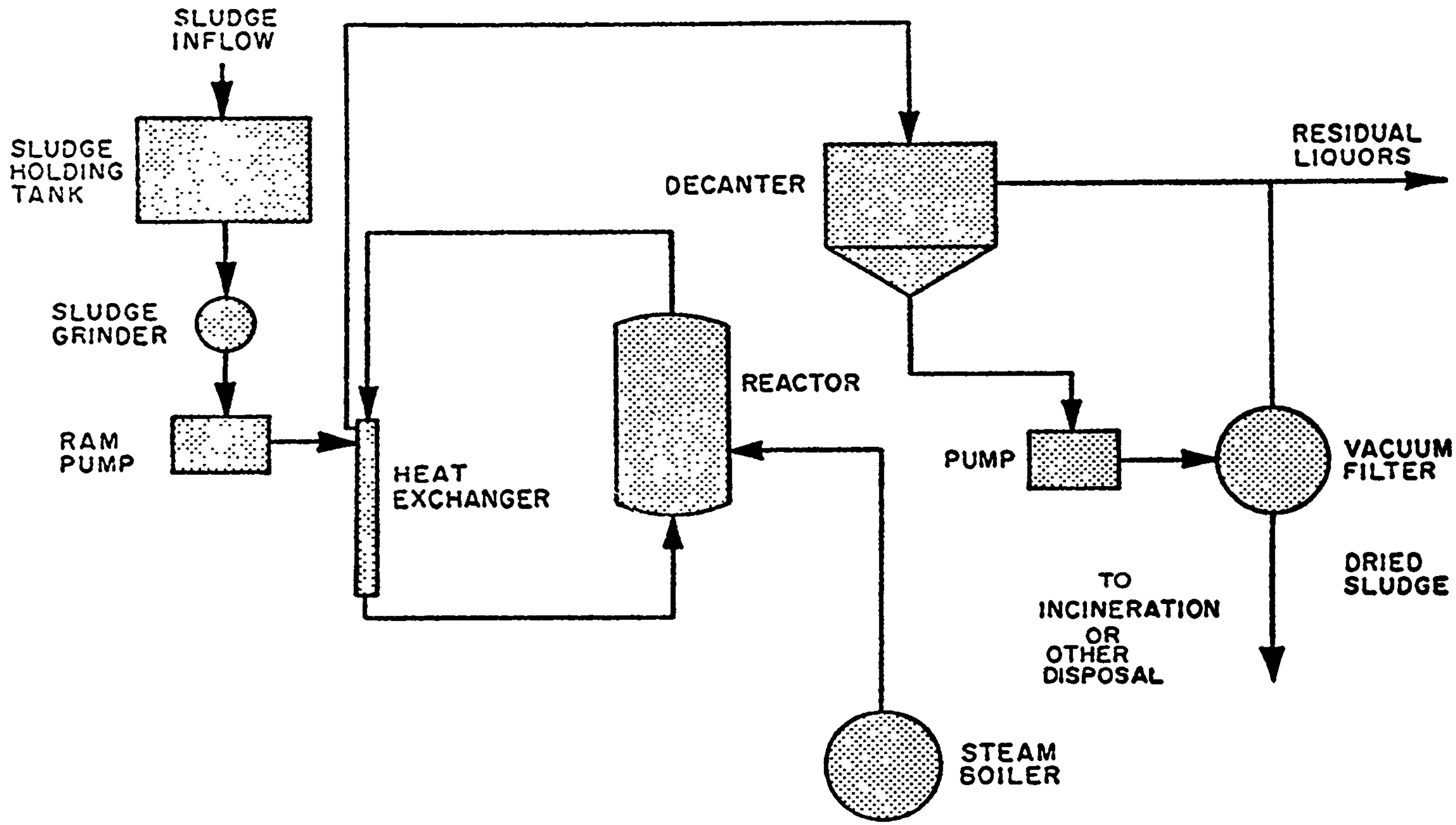
The detention time for the sludge in the reactor vessel is thirty minutes. After this period the sludge is again passed through the heat exchanger where heat is transferred to the incoming sludge. The processed sludge is then pumped to a decanting vessel. The supernatant, which is quite potent and dark purple in color, is drawn off and must undergo subsequent treatment. The settled sludge is then conditioned for mechanical dewatering.

Manufacturers claim that filter cake with moisture content as low as 40 percent can be obtained if filtration is preceded by the Porteous process. However, verification of this figure based on independent operating tests is not readily available. Cost curves have been developed and are presented in Figure III-C-14 (Ref. 154). Information in the literature (Ref. 154) indicate the rough equivalence of heat treatment with combined digestion and sand bed drying.

d. Farrer Process Heat Treatment

The Farrer process is illustrated in Figure III-C-15 and can be described as follows:

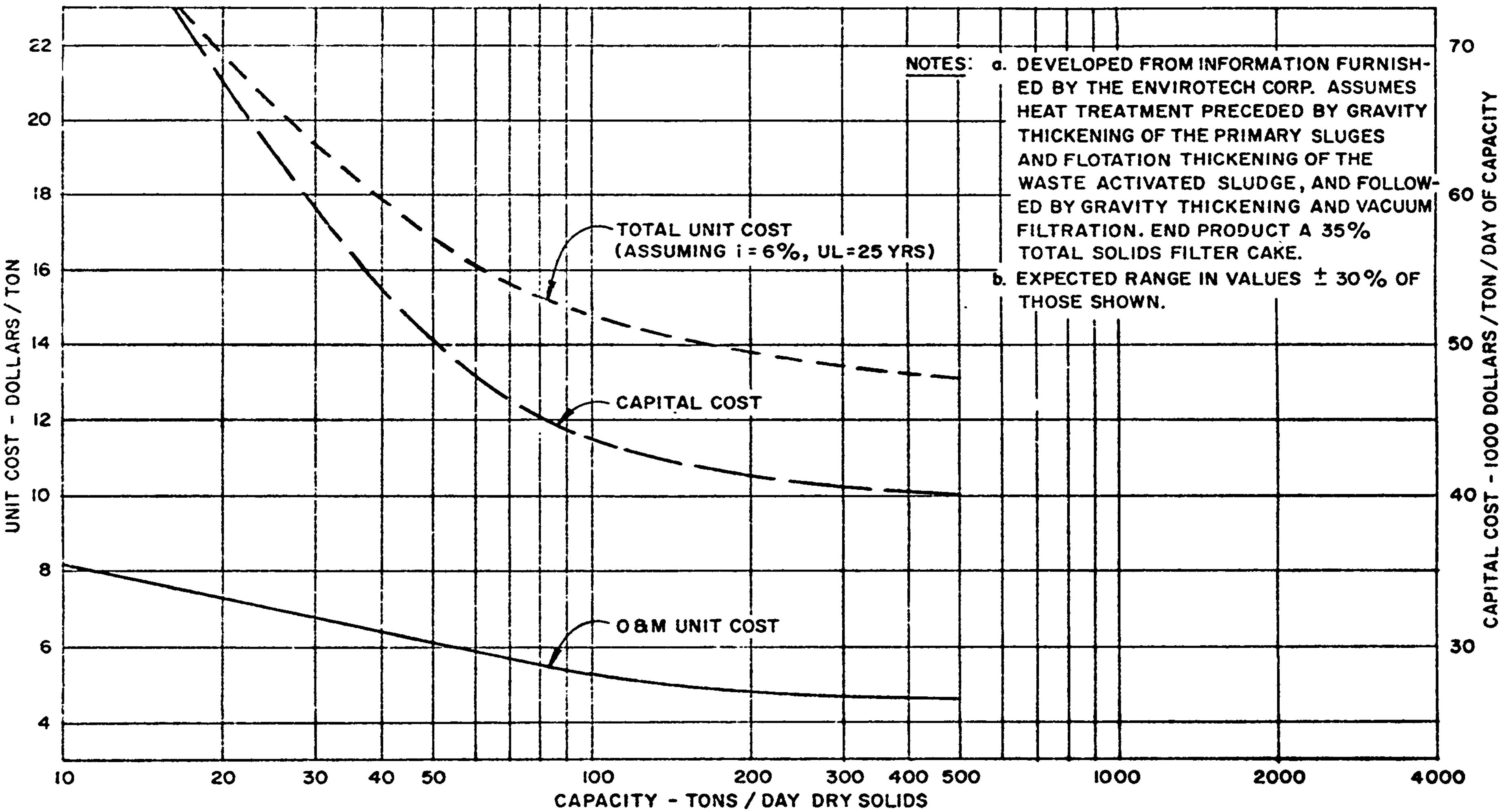
Raw sludge is first thickened, ground and then pumped to the first stage of the heat exchanger. The first stage of the heat exchanger is referred to as the pre-heater and it is here that heat is absorbed from previously conditioned sludge. It then flows to the second stage where heat from the boiler increases the temperature to the operating range of 360°-380°F. The sludge then flows into the reactor or third stage of the heat exchanger. After heat exchange with incoming sludge, the conditioned sludge is pumped to settling tanks.



PORTEOUS PROCESS

Figure III - C - 13

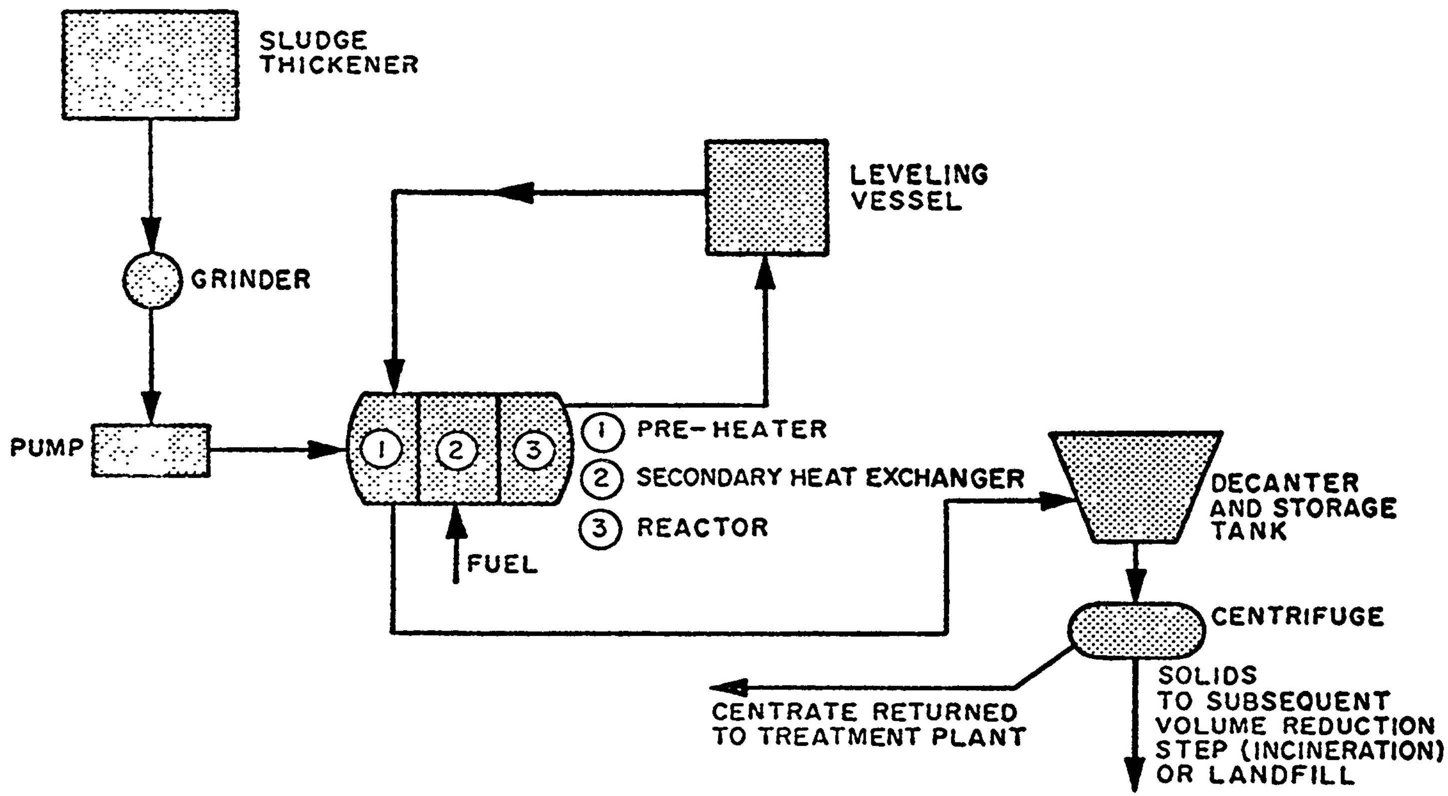
PBQ & D, Inc.



HEAT TREATMENT DEWATERING PORTEOUS PROCESS COST CURVES

(JANUARY 1972 ADJUSTED)

Figure III-C-14



THE FARRER PROCESS

Figure III-C-15

The manufacturer's description of the Farrer process indicates that subsequent mechanical dewatering can result in filter cake moisture of 45 percent. There are presently no installations in the United States utilizing the Farrer process, although over twenty applications are reported in Europe. For this reason literature verification of process performances was not readily available.

e. Carver-Greenfield Process

The Carver-Greenfield process of heat treatment is illustrated by the flow-chart presented in Figure III-C-16. This process differs from the previous two in that it is primarily a reclamation process. It most likely has a larger application in the field in industrial wastes for the recovery of proteins, starches, fertilizers and chemicals (Ref. 202). However, it can be utilized as a drying technique in the sewage sludge treatment process.

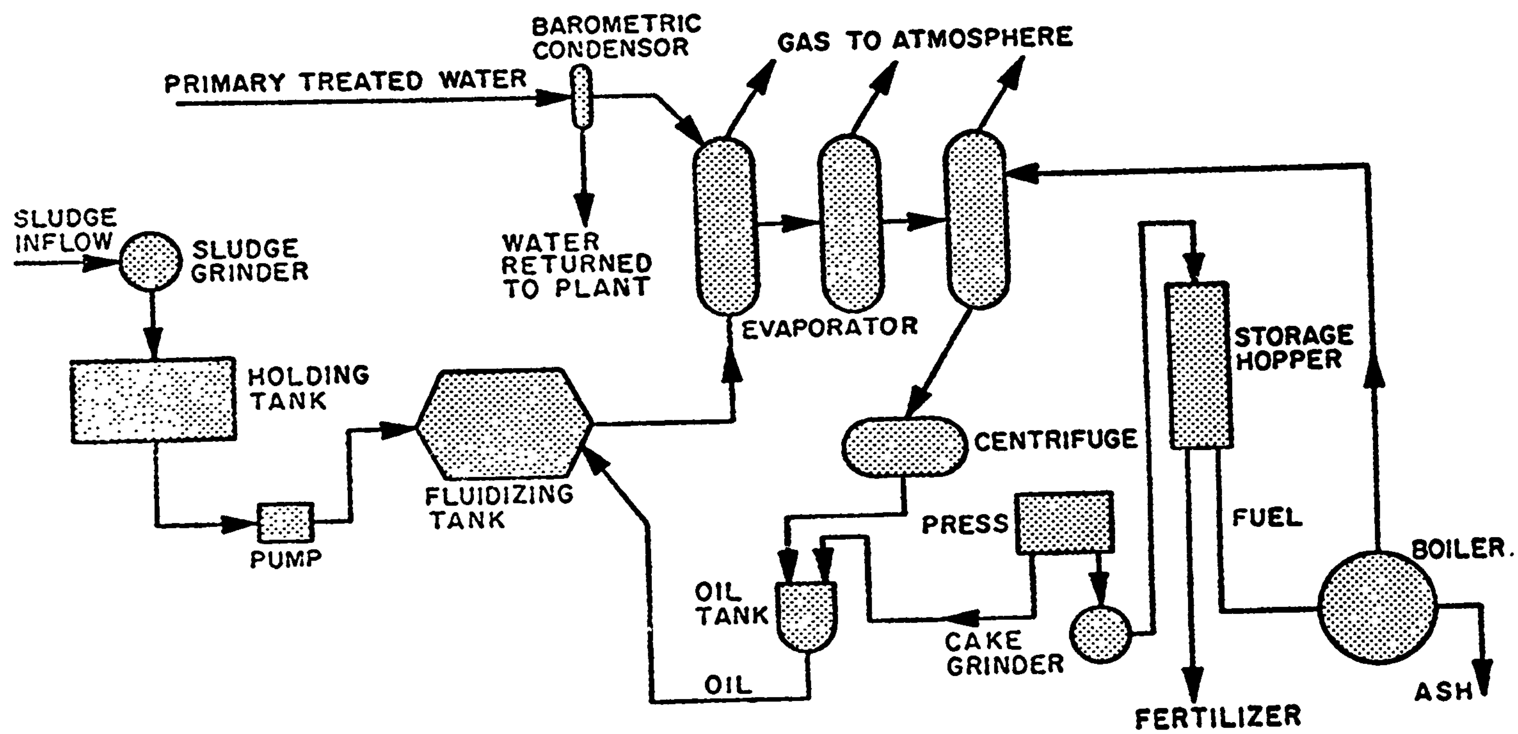
The sludge is first ground and then mixed with oil in the fluidizing tank. The mixture is then passed through three evaporation stages. The evaporators are fed by steam from a boiler. The addition of oil facilitates the flow of sludge through the plant. The dried sludge is then centrifuged and processed through a hydraulic press. These two steps serve to recover the oil and other desirable materials. The resulting cake is ground and then applied to the boiler furnace as fuel. It is possible to utilize some of the dried cake as a soil conditioner.

Unfortunately there are no descriptions or process performance data readily available in the literature for application of this process to the disposal of sludge.

The most significant advantage of the Carver-Greenfield process is that the requirement of chemical conditioning prior to mechanical dewatering can be eliminated.

f. Flash Drying

Flash drying is a heat drying technique which has decreased in popularity in recent years. It was at one time favored in many locations due to the flexibility it offers of drying or incinerating sludge. However, the demand for the utilization of dried sludge as a fertilizer has not increased as was anticipated. This low demand coupled with the fact that the flash drying system is more complex than multiple-hearth equipment has led to an increased number of selections of the latter process. The flash drying process can be described as follows.



THE CARVER-GREENFIELD PROCESS

Figure III-C-16

The sludge is vacuum filtered to approximately a 75 percent moisture content. It is then discharged to the paddle mixer where it is thoroughly mixed with previously dried sludge. This action is reported to be capable of reducing the moisture content to approximately 35 percent (Ref. 93). The mixture then enters the cage mill where the damp sludge particles are turbulently mixed and dried by hot gases. The hot gases are conveyed to the cage mill by air ducts from the incinerator. The hot gas stream has a velocity of several thousand feet per second and a temperature of 1100°F (Ref. 122). The mixing and drying occurs rapidly, hence the name "flash drying."

The drying gases carry the sludge particles upward to a cyclone where the two are separated by centrifugal action. A portion of the dried solids are returned to the paddle mixer while the remaining portion can be incinerated or utilized as fertilizer depending upon demand.

The incinerator requires auxiliary fuel to complete combustion of the dried sludge particles. This auxiliary fuel requirement is most commonly met by using #2 fuel oil. If refuse and sludge are incinerated together, the heat liberated from the combustion of the refuse can supply a part of the supplementary heat requirement. Such mixed incineration may contribute, however, to experienced particulate emission control problems observed at such flash drying installations (Ref. 99).

Cost information for flash drying, like that for heat drying in general, is rather sketchy (Ref. 154). No doubt the unit costs for flash drying are reflected in the higher levels of those briefly discussed for heat drying in general (see the last paragraph in Section III-C-3b). In one study comparing heat drying with incineration where both specialized incineration and incineration-or-heat drying functioning units were involved, the following was indicated:

1) Heat drying unit costs with dual-mode units was about double the unit costs of incineration with specialized incineration units.

2) Incineration unit costs with the dual-mode units was about 17 percent higher than that with the specialized units.

3) High temperature deodorization, commonly required at new heat drying and incineration installations, increases the cost between 20 to 30 percent. Without deodorization equipment, the operation costs comprise about 60 percent of the total unit costs.

g. Wet Oxidation

Within the last ten years, considerable interest has developed regarding the wet oxidation process. The low temperature-low pressure process variation can be used for heat treatment. Some other process variations subject organic sludges to high temperatures and pressures in the presence of oxygen. Under these conditions oxidation readily occurs, resulting in cell structure changes, liquefaction and consolidation. The solids volume is reduced with a further benefit of improved solid-liquid separation when the output is passed into a separation device.

Initial capital costs are relatively high due to the necessary equipment required which must be capable of withstanding high temperature and pressures. Much of the equipment is constructed of stainless steel to inhibit corrosion. Operating costs are also relatively high because of the need to oxidize the sludge at temperatures of 250°-700° F and pressures up to 1700 psi. Once the process starts, sufficient heat is usually generated to maintain the temperature required. The wet oxidation process is quite compact, is not affected by usual materials toxic to biological oxidation and can produce a consistent and stable end product. To date most installations have been made at small to medium-sized plants since the economics generally favor other processes as the amount of sludge increases.

The wet oxidation process is examined in greater detail in the section of this report entitled High Temperature Volume Reduction. Cost information for the heat treatment process variation is very sketchy (Ref. 154). It would appear that capital costs and most elements of operation and maintenance costs are about the same as those for the higher temperature and pressure combustion process variations. Fuel costs, for example, appear to be about four times those experienced in the combustion process variations.

h. Incineration

Incineration is discussed in detail in Technical Appendix Chapter III-D. A typical multiple-hearth unit is illustrated in Figure III-C-17. It is sufficient at this point to mention that incineration provided the greatest sludge volume reduction of any process presently in use. Due to economic considerations, sludge is usually partially dewatered by other processes prior to incineration for final volume reduction. When proper solids handling equipment is used, incinerators can be used for all types of sludges. Sludges of low water content can often become self-sustaining fuel after initial firing, thereby reducing fuel costs. New and changing air pollution control requirements are certain to increase the costs of incineration; however, the technical capability of meeting those requirements is presently available.

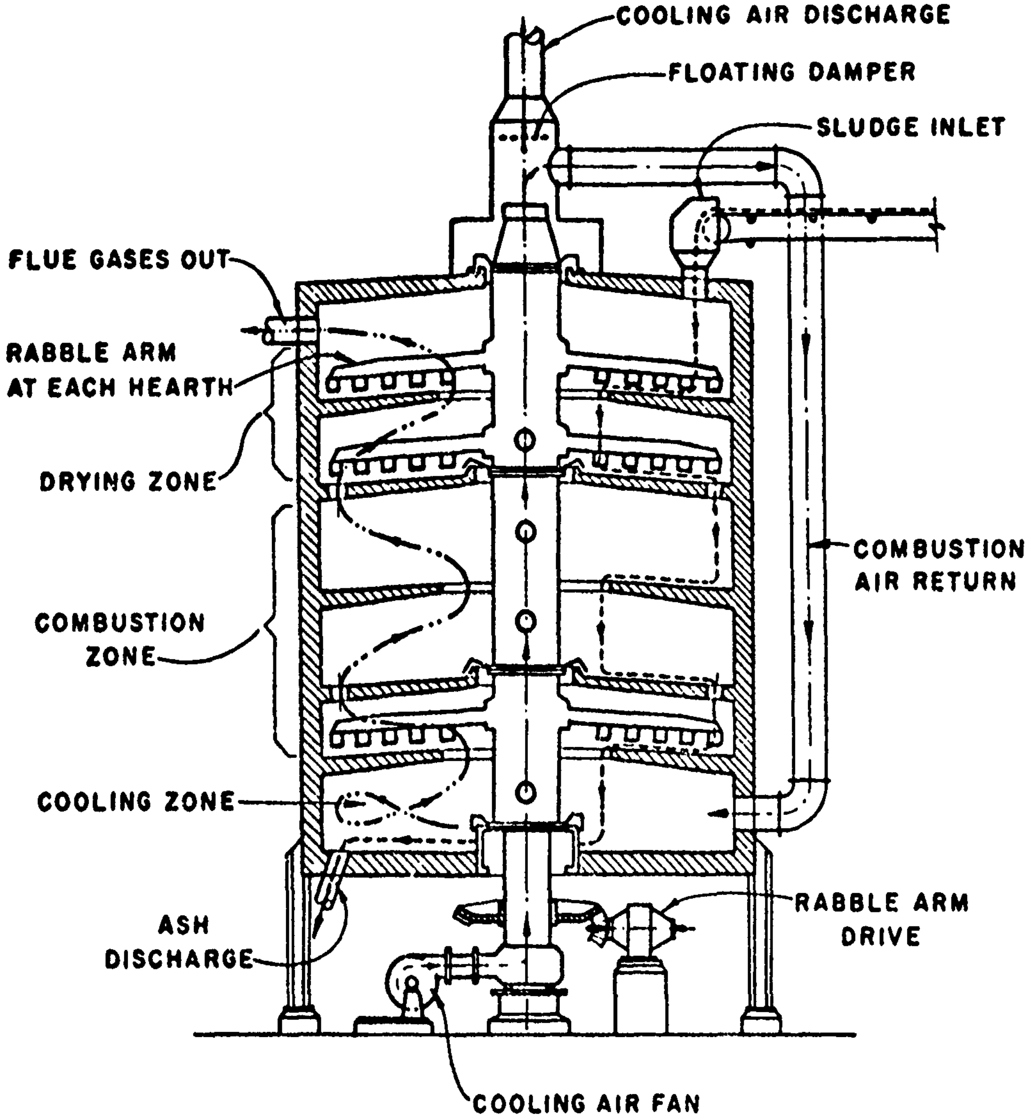
4 - Sludge Conditioning

Associated with the volume reduction methods discussed above are several sludge conditioning processes. These sludge conditioning processes do not actually reduce sludge volumes but greatly facilitate volume reduction during subsequent dewatering operations. The most common of these processes is chemical addition or chemical sludge conditioning. The mechanisms vary and in some cases are not completely understood. Generally, they are thought to assist in coagulating or forming colloidal flocs of the solids dispersed in the sludge and thereby enhance their subsequent flocculation, further agglomeration and ultimately their removal from the larger water mass. As mentioned previously, some sludge volume reduction methods are infeasible without sludge conditioning.

The chemicals most often used are lime, ferric chloride, alum, chlorine, and polymers. The addition of chemicals serves mainly as an aid to coagulation where, under the proper conditions, the sludge solids form porous agglomerates which are more readily dewatered. The pH of the sludge sometimes requires adjustment for optimum dewatering and this adjustment is best done through chemical addition.

5 - Future Volume Reduction

Extensive research and development is being conducted in improving present sludge handling procedures and equipment. Extensive efforts are also underway to devise new methods and procedures for



TYPICAL SECTION

MULTIPLE HEARTH INCINERATOR

(from Fig. 19.1, Ref. 154)

Figure III - C - 17

solids handling. Some results are evident from all these efforts and there is every expectation that a number of other new methods will become available within the next 20 years. It is important, however, to continue to evaluate these new methods carefully and critically. Much of the effort is conducted by proprietary interests, who due to their involvement, may not always include a completely objective analysis of benefits and detriments of a particular process. With independent analysis and increasing scale of application, more complete evaluations should become available. The question of how process performance varies with flow can be answered only after a number of installations of varying capacity have operated over a period of years. Many innovative approaches to wastewater and solids treatment have appeared attractive for small scale applications, but when applied to large scale applications the disadvantages have often outweighed the benefits. Reliability of operation and sensitivity to variations in loadings become important factors. Economic and technical constraints often become critical determinants for large plants whereas some inefficiency and overdesign may be tolerable for small plants. A number of recent developments are presently being installed and analyzed in small to medium sized treatment facilities. Some of these show promise. It also appears that refinements to presently used methods will bring increased application of those methods.

Improvements in heat treatment and wet oxidation equipment and applications will probably increase the use of these processes. The compact arrangement, lack of interference by toxic materials, and suitability of end-products are important advantages of these processes.

Additional improvements in pressure dewatering or filtration may be possible since this method appears to offer the potential of greatest volume reduction other than heat drying or incineration. A major advantage of pressure dewatering is that the material being dewatered is not changed or "destroyed" as in incineration and therefore offers considerable potential for recovery and use for fertilizing and soil amendment. Pressure dewatering application will probably depend on the improvement of continuous operation efficiencies and on the development of rugged membrane materials.

Oxidation of sludge with chlorine has been developed. Some advantages apparently make this process suitable for small installations. Its application to larger installations will depend on cost, availability of chlorine and characteristics of the sludge.

Continuing development of screens and hydrasieves may result in useful sludge dewatering methods. Problems of screen clogging appear closer to being solved. The type of sludge applied has considerable influence on this. Generally, screens and hydrasieves are quite simple mechanically and are relatively inexpensive. New materials, cleaning processes, and fabrication techniques allow significant modifications. Operation costs should be minimal unless extensive cleaning is required, in which case other methods would probably be used. One area of required development is the improvement of retention and concentration of solids in the screens and hydrasieves.

Freezing is being investigated as a possible sludge volume reduction method. However, many problems remain which must be resolved before freezing will become a feasible process. The City of Milwaukee has done some work evaluating this process and other investigators have used sludge freezing methods for conditioning prior to dewatering. Sludge conditioned in pilot studies could be dewatered by gravity draining with resulting solids concentrations comparable to vacuum filtered sludges. Initial estimates indicate that yields are 10 to 20 times those normally obtained with vacuum filtered chemically conditioned sludges.

Ultra-filtration is an extension of other filtration processes through use of different filter media to increase the liquid throughout and solids retention and, as a consequence, improve the filter efficiencies. Generally, the investigative work to date has studied the pressurized mode of ultrafiltration. Finding filter media which are both tough and durable and have small pore sizes has been the major problem. Small amounts of lipoid carryover can greatly increase operation problems. Furthermore, initial work indicates relatively high costs. Unless the indicated costs are reduced substantially it does not appear than ultrafiltration will be competitive with existing technologies. If performance requirements should change significantly and much less carry-through would be acceptable, it is possible that ultrafiltration could become more attractive.

Ultrasonic methods have also been investigated for wastewater treatment and phases of this investigation have related to volume reduction. Apparently some benefit derives to subsequent dewatering procedures if solids are subjected to ultrasonic treatment.

Evidence indicates that some of the water bonds are weakened by ultrasonic exposure but much is still unknown. It appears that most

benefits from ultrasonic treatment of sewage sludges will fall into the classification of sludge conditioning rather than actual sludge volume reduction.

Irradiation of sewage sludges with gamma radiation has been studied in an attempt to determine beneficial effects. It appears that some improvement in settleability and filtration dewatering does in fact occur. However, the costs are such that gamma radiation is not competitive with existing methods. The restrictions on use of such a process due to potential hazards require highly qualified operation personnel and special measures to meet environmental concerns.

6 - Digestion

Anaerobic digestion is utilized extensively throughout the world for sludge decomposition and volume reduction. Aerobic digestion is also utilized widely although to date it has generally been applied only in small plants, due to operating costs, or with wastes of high sulfide content in domestic water. As the economies and reliability of raw sludge handling equipment continue to improve, a number of installations have eliminated the need for digestion facilities by going directly to incineration or some form of heat conditioning stabilization. Where sludge storage is required, however, some digestion usually takes place.

Digestion is a biological decomposition process (anaerobic or aerobic) resulting in gasification, liquefaction, stabilization, destruction of colloidal structure, and the consolidation or release of moisture; the last producing a significant volume reduction. The digestion process can take place under closely controlled conditions and, consequently, is very effective, reliable, and economical. On the other hand, when the digestion process gets out of control, the results can be very unsatisfactory with the establishment of noxious conditions. There can be considerable difficulty in re-establishing control. Anaerobic digestion usually takes place in covered tanks where the end products are water, gas (principally methane and carbon dioxide), and a stabilized, humus-like sludge which has fuel and fertilizer value. The methane gas can be used as a fuel source or wasted using controlled burning methods, depending on the needs and specific economics of each situation. The fuel value of the sludge generated methane is usually about 25 to 40 percent less than the fuel value of natural gas. However, a number of installations utilize sludge gas for heating digesters and buildings and for powering pumps and generators. Due

to the corrosiveness of unwashed sludge gas and the need to employ the use of extensive mechanical equipment and skilled operation, sludge gas normally is not used for driving equipment other than for sludge heaters, except at larger treatment facilities.

The anaerobic digestion process is essentially a two step biological process which through bacterial action converts organic material first to an organic acid and then to methane, carbon dioxide, water and residual materials. The residual matter, although having significant concentrations of nitrogen and phosphorus, does not have as high concentrations of these nutrients as in most commerical fertilizers. Therefore, digested sludge is not competitive on fertilizer value alone. The most successful example of selling sludge has been at Milwaukee, Wisconsin, where brewery wastes give the sludge high fertilizer value. The digested sludge is dewatered, dried, and sold under the trade name of "Milorganite". Other attempts at commerical utilization of sludge have been less successful although a number of examples exist of successful sludge utilization when profit is not a major criterion. Considering that sludge disposal is a major cost item of any wastewater treatment operation, any offset in the cost should be considered a benefit. Furthermore, with the interest in recycling waste products which has finally become evident, any beneficial reuse of sludge can also be considered a social benefit.

Depending on actual operating procedures, sludge can concentrate in the bottom of a digester and the supernatant liquor can be decanted off. Significant volume reduction results from normal digestion practice and, therefore, it can be considered as a volume reduction method even though digestion is usually followed by one or more further dewatering procedures. Since digestion is a biological decomposition process, it is only effective for organic sludges and animal and vegetable oils and greases. Grit and lime sludges generally do not affect digestion except that effective tank capacity is reduced as inorganic solid material builds up. Toxic solids are very detrimental to the digestion process since the process relies on natural organisms which exist in a delicate balance. This balance can be disturbed by other stresses such a improper feed rates, variation in temperature, or introduction of toxic materials into the digester.

Digestion alone is an inefficient and expensive volume reduction method. Used in conjunction with other dewatering methods, digestion offers many advantages to solids handling procedures. It should be noted, however, that digester installations have a high initial capital cost due to the tank structure and mechanical equipment required.

The advantage of anaerobic digestion over aerobic digestion as a volume reduction process lies in its somewhat greater ability to reduce total solids content by gasification. In addition to carbon dioxide and water vapor, gaseous end-products of both processes, anaerobic digestion also produces methane, carbon monoxide, nitrogen and hydrogen gas, hydrogen sulfide, ammonia, and mercaptans. Aerobic digestion has no gaseous by-products incorporating nitrogen, sulphur, or hydrogen. Some typical anaerobic sludge gas analyses show methane content ranging between 61 and 73 percent, carbon dioxide content between 20 and 32 percent, carbon monoxide between neglible to 1 percent, hydrogen from 1 to 4 percent, hydrogen sulphide between neglible to 3 percent, and nitrogen gas between 1 and 5 percent (Ref. 9.)

Digestion Methods - Present Practice. Present anaerobic digestion practice is based on two-stage heated digesters with mixing and active digestion in primary digesters and solids separation and holding in secondary digesters. Digestion is normally carried out in the mesophilic temperature range. In larger installations, sludge concentration is provided both before sludge addition to digestion tanks and after active digestion. Digestion is carried out in alkaline conditions to promote formation of methane and suppress formation or carbon dioxide.

Many variations in facility design are used under these basic criteria. Heat is applied by direct steam injection, underwater gas burners, or external and internal heat exchangers.

Mixing in primary digesters in provided by internal mixers, pumped mixing, and gas recirculation. Several means of scum suppression are used.

Some digesters have operated in the thermophilic temperature range, but sensitivity to variations in feed rate or temperature has limited prolonged use.

Problems in maintaining good mixing have limited the maximum effective diameter of digestion tanks. Tanks over one hundred feet in diameter present excessive problems.

Digestion Methods - Variations in Processes. Anaerobic digestion is subject to a number of variations depending upon sludge characteristics, concentration methods used, and final disposal or use.

One variation widely used in Europe but utilized in only one installation in the United States is the use of a deep secondary digester. A digester 150 feet of more in depth is capable of concentrating the sludge by compaction to 20 percent or more solids content. This can obviate further concentration prior to reuse of disposal.

Another variation is the use of only single stage digestion with removal of digested or partially digested solids for subsequent concentration and disposal, with either chemical or heat treatment being used to facilitate dewatering.

A number of new plants incorporate a combination of partial aerobic digestion followed by anaerobic digestion. While this is usually accomplished by contact stabilization in a process similar to activated sludge treatment, it is sometimes carried out in a process separate from the wastewater treatment on the liquid sludge prior to discharge to disgestion.

Variations in process are dictated by economics in each specific application depending upon characteristics of each sludge and final disposal method utilized.

Digestion Methods - Current Trends. Current trends in digestion processes include methods of facilitating dewatering and reducing the volume of digestion capacity required. The volume of digestion capacity required is greatly affected by water content of liquid sludges. Water content can be reduced by sludge concentration prior to delivery to the digester or by chemical treatment in the primary sedimentation process, or both.

Greater utilization of digester capacity is also obtained by separate disposal of skimmings and screenings, which tend to form scum layers in digestors, and by removal of the fine grit fractions from the sludge, the latter tending to form bottom deposits in the digesters.

Brief incomplete digestion followed by heat treatment and concentration is an increasingly used system. Direct filtration and centrifuging of partly digested or raw sludges have been applied but high chemical costs and odors have been a problem.

Digestion Methods - Future Process Innovations. Developing processes in physio-chemical wastewater treatment will produce sludges of greatly increased volume and with characteristics unsuited

to conventional anaerobic digestion. Lime sludges will probably be concentrated and disposed of through composting, directly to the land, or by means of incineration with the recalcined lime and other fractions being recovered.

Wastewater treatment employing organic materials utilizing sorptive techniques for increased removal of biologic toxicants and organic residuals shows promise. Such sludges may be digested by conventional means or concentrated and stabilized by heat treatment or aerobic digestion.

While some development work has been done on nutrient chemical addition to digesters, fermentation digestion and digestion at high temperatures, the costs and problems of process control indicate that these innovations are not yet practical for other than special applications.

Digestion Methods - Suitability of Organic Solids for Anaerobic Digestion. Organic solids from sewage treatment processes may be digested in heated digestion tanks with solids reductions in the order of fifty percent and production of combustible gas as a by-product. Vegetable and animal fats can also be digested. Petroleum oils and solvents do not breakdown under normal digestion but may indeed inhibit digestion by tending to form a scum layer and occupying inactive space in the digester.

Active digestion is encouraged by mixing, uniform temperature, uniform feed rate, maintainence of pH above 7, and seeding with active organisms. Digestion may be inhibited by toxic compounds, such as metals and solvents, reduction in digestion time either by scum or grit accumulation, sludge feeding, temperature variations or inadequate mixing. While toxic materials tend to inhibit digestion, many toxic compounds such as phenols can be accommodated at relatively high levels if tolerant organisms are developed and uniform feed is maintained. Sludge elutriation prior to digestion has been effective in reducing toxic content of sludges to permit digestion.

Although water content does not appear to affect digestion rates, high water content reduces digester capacity for solids and low water content may make adequate mixing and maintainence of uniform temperature difficult. Sludges at three percent solids require twice the digestion capacity of six percent sludges. At solids contents over ten percent, uniform mixing may be difficult. Mixing devices of high velocity or impellers with high speed tend to homogenize and break down solids making subsequent concentration and dewatering difficult.

The three major components of organic sludges are water, volatile solids, (predominantly digestable organics) and non-volatile solids (ash and grit). Water may range from 90 to 98 percent of the liquid sludge. The volatile fraction of the solids may range from 50 to 80 percent by weight, but this range may be increased with the presence of industrial wastes and combined sewers, and with some wastewater treatment processes.

Digestion of volatile solids produces gas and water, with the water production causing a decrease in percent solids in digested sludge. While the sludge can be concentrated by elutriation or other means prior to discharge to second stage digestion, secondary digestion is usually utilized for concentration as well as storage for further processing. Some sludges separate readily in unmixed secondary digestion permitting decanting of relatively clear supernatant from the tank. Homogenized or finely divided sludges resist gravity separation and must be dewatered by mechanical or physio-chemical means.

Digestion Methods - Suitability or Organic Solids for Aerobic Digestion. Aerobic digestion is widely used in small plants, usually under 1 MGD capacity, and usually takes the form of a variation of the activated sludge process where the aeration of sludge and incoming wastewater solids is integrally combined. It produces aerobically digested sludges considerably reduced in volume through the 'destruction' of most of the volatile fractions. Its limitation to small plants is due to the cost of the process, primarily that of power. At the 1 MGD level, total annual costs for separate aerobic digestion could be within 5 percent of those for anaerobic digestion. The ability of the process to handle sludges with high salt content without the formation of hydrogen sulphide makes the process desirable in this special case.

Aerobic digestion has been successfully used on high-organic industrial waste solids. Where these solids are concentrated, rapid digestion has been obtained by aerobic digestion at temperatures up to 200° F. If the solids cannot be concentrated, the cost of heating and aeration becomes excessive.

With special industrial waste solids, aerobic digestion can be obtained by heating under pressure and oxidation by reaction with air, oxygen, chlorine, or other oxidants. With certain collodial solids, this is the most efficient means of digestion and treatment.

While the first stage of aerobic digestion may approximate conditions of the activated sludge process, it is essentially a chemical oxidation of organic solids rather than a biologic action which takes place in anaerobic digestion.

Digestion Methods - By-products. Combustible gas is the by-product of sludge digestion. Proper anaerobic digestion produces a gas with 65 to 70 percent methane, 25 to 30 percent carbon dioxide, together with small amounts of hydrogen sulfide, nitrogen and hydrogen ranging, respectively, from 0 to 3 percent, 1 to 5 percent, and 1 to 4 percent. Under acid digestion, carbon dioxide is the primary gas produced. It has little heat value and its production is associated with foaming problems. Prior to its use, this gas should have hydrogen sulfide and water vapor removed. Hydrogen sulfide levels are greatly increased if significant seawater is in the wastewater flow.

Gas production ranges from 15 to 19 cubic feet per pound of volatile solids digested, measured at six-inch water column pressure. Heat value is 640 to 700 BTU per cubic foot. If carbon dioxide is removed from the gas, it will approximate the heat value of the natural gas ranging from 900 to 1050 BTU per cubic foot.

Research on fermentation digestion of sludge has indicated that alcohol can be produced, but for domestic wastes the process has not been practically developed. This is a type of anaerobic digestion.

All types of solids removed in wastewater treatment plants have heat value which can be recovered if the water content is low enough. On burning, approximately 2200 BTUs are required to drive off a pound of water. Table III-C-5 lists available information on heat values of various types of sludge and other residual wastewater solids:

Table III-C-5
CHARACTERISTICS OF WASTEWATER SLUDGES AND RESIDUAL SOLIDS ON A DRY WEIGHT BASIS*

Type	% Combustible** (Total Volatile Solids)	%Ash (Total Fixed Solids)	BTU/Pound
Raw Sludge	60-80	20-40	9,900-13,400***
Digested Sludge	50-75	25-50	5,000-10,000***
Grit	20-50	50-80	2,000- 6,000
Screenings	50-90	10-50	5,000- 9,000
Grease & Scum	60-90	10-40	10,000-17,000

(Ref. 88, 113, 215)

*As percent of total dry solids

**Percent loss by iginition - includes combustible organics and volatized inorganics

***These values reflect estimates of increasing grease content of primary sedimentation sludges due to increasing use of garbage grinders progressively less saving of grease, these resulting in increased diversion of grease to sewers.

Digestion Methods - End Products of Anaerobic Digestion. Proper sludge digestion produces stabilized solids which may be dewatered and used as a fuel for thermal energy. It is also used for soil amendment, either directly or as a nitrogen and trace element source in the composting of cellulose materials. Research has indicated that dried sterilized sludge has a potential use as stock food when mixed with molasses.

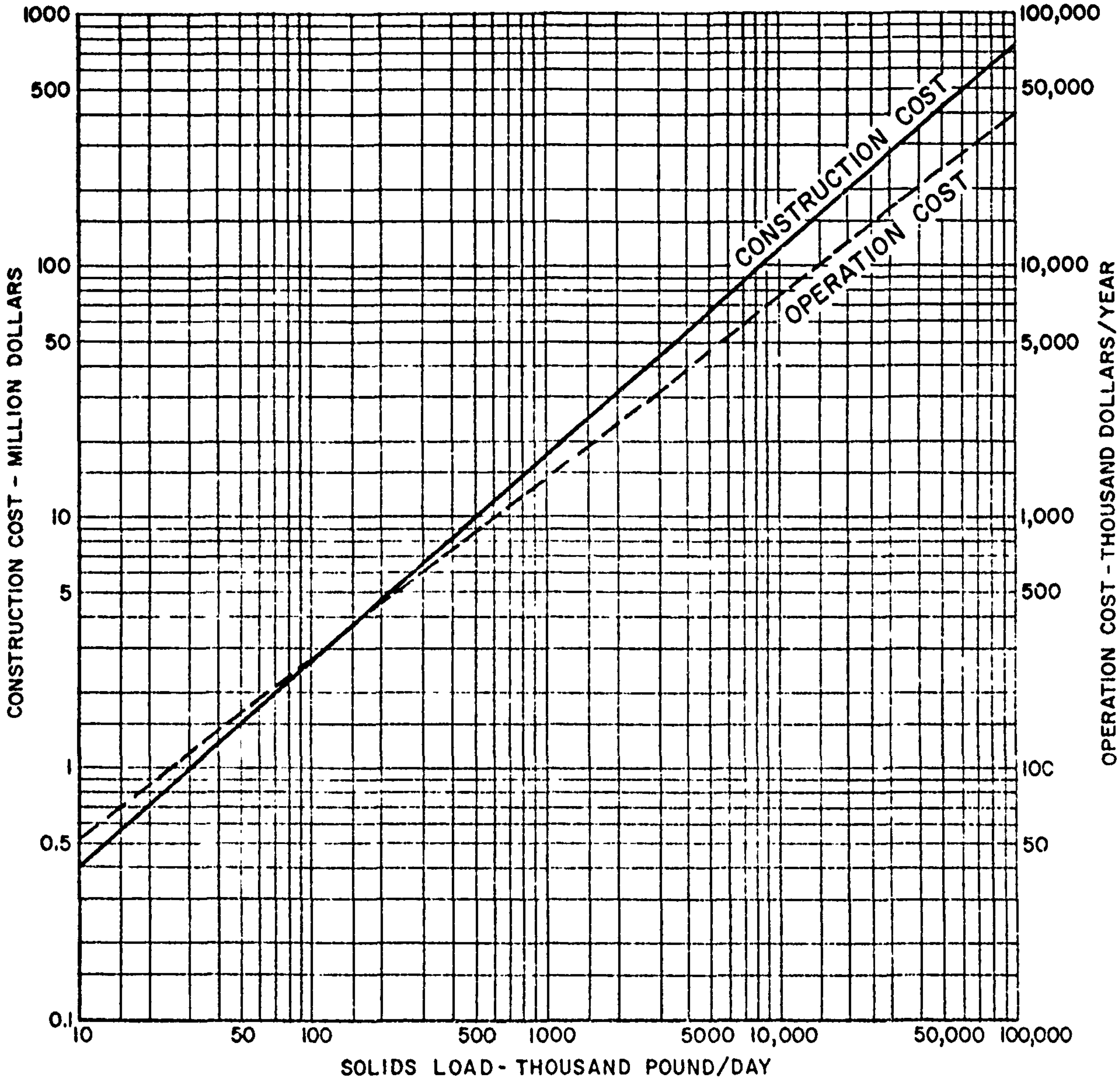
If sewage treatment processes include comminution of solids and discharge of skimmings to digesters, sludge quality for reuse is greatly decreased due to undigested oils, grease and plastics in the final product.

Unless concentrated between stages, sludge from the digestion of combined primary and activated sludge will contain approximately four percent solids, due to the production of water during the digestion process in which approximately 50 percent of the solids are broken down.

Unless the sludge is heat treated prior to dewatering, lime or other coagulant aids are needed for efficient dewatering. Unless it is applied to land or otherwise used in liquid form, the sludge is usually dewatered to 60 to 80 percent water content and is used in cake form, or is dried or incinerated. Cake at 70 percent or less water content will usually support combustion in a properly designed furnace.

Sludges contain about 0.8 percent phosphorus and about 2 percent nitrogen on a dry weight basis. (For a more detailed discussion of this, see Section III-G-6d.) Sludges with some industrial wastes have been found to have as much as 10 percent nitrogen. In addition to these low level fertilizing elements, sludge contains most trace elements necessary for plant growth. Only rarely are toxic elements present in detrimental amounts if digestion has not been inhibited.

Cost curves have been developed for two-stage anaerobic sludge digestion and are presented in Figure III-C-18 and III-C-19 (Ref. 29).



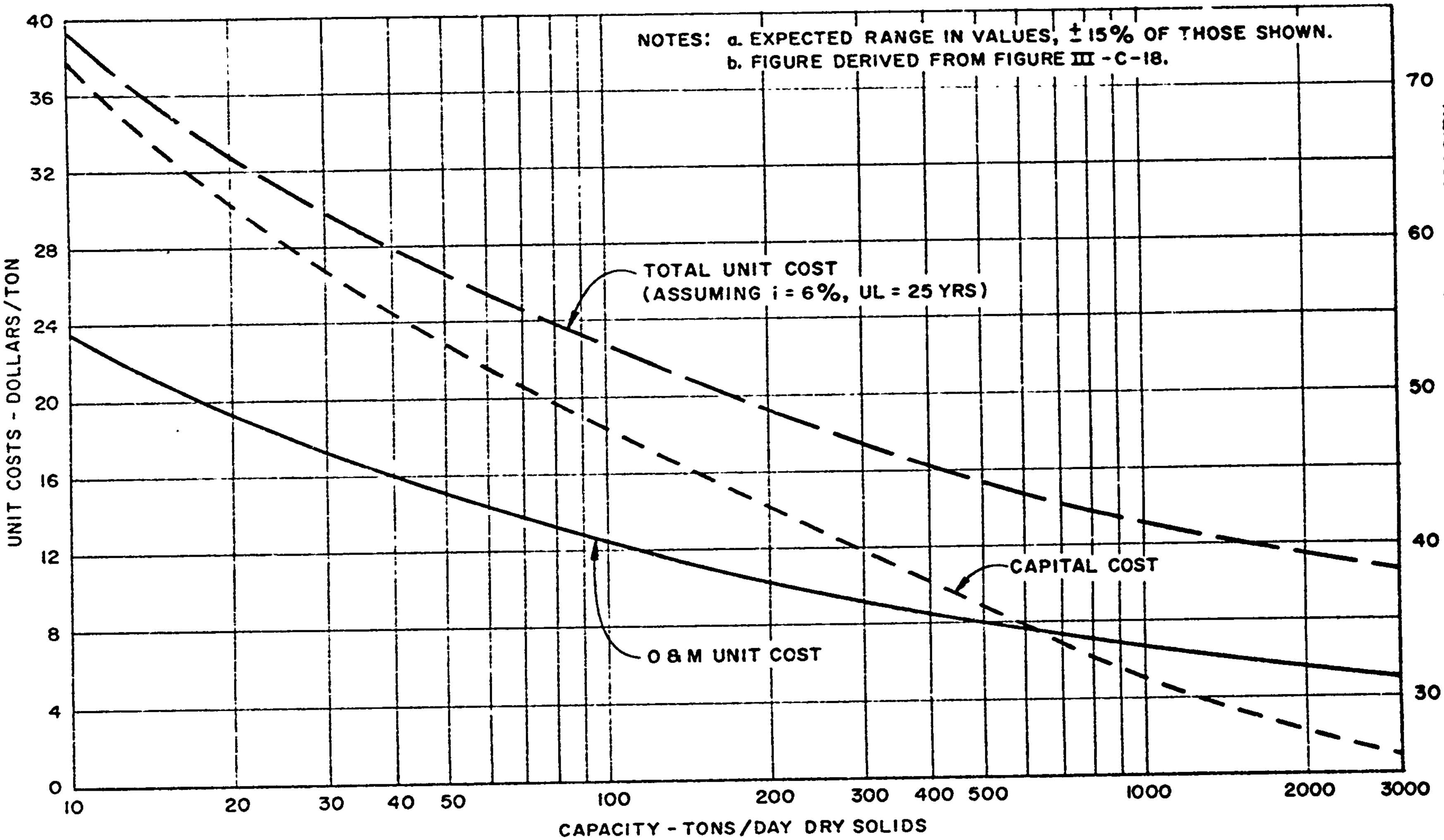
(from Ref. 29)

ANAEROBIC DIGESTION COST PROJECTIONS

TWO STAGE SLUDGE DIGESTION
(JANUARY 1972 ADJUSTED)

Figure III - C-18

PBQ & D, Inc.



(from Ref. 29)

TWO STAGE ANAEROBIC SLUDGE DIGESTION COST CURVES

(JANUARY 1972 ADJUSTED)

Figure III - C-19

7 - Summary of Non-Combustion Volume Reduction

Table III-C-6 concisely summarizes this chapter on non-combustion volume reduction. Figure III-C-2,4,7,9,12,14,18 and 19 present the cost curves developed. Particular attention is directed at the notes contained in these figures. The cost picture is far from being as clear cut as may be assumed from a quick scanning of these figures. The kinds of sludges and particularly the preconditioning have dramatic effects on the unit costs. The rough equivalence between vacuum filtration and centrifugation reported in the literature is generally borne out. The rough equivalence between heat treatment dewatering versus combined digestion and sand bed air drying, however, is not. In the range of 10 to 1000 tons per day, the values developed for combined digestion and sand bed drying were about double those developed for the heat treatment dewatering alternate. The combination of preliminary heat treatment and sand bed drying also appears to cost more in this same range, from 32 to 42 percent more. From the cost values developed, a comparison between heat treatment dewatering and chemical conditioning dewatering appears to indicate near equality at the 20 dry tons/day range with an increasing relative higher costs with chemical conditioning toward the higher loading ranges. The heat treatment process produces a 35 percent solids sludge cake compared to the 21 percent solids sludge cake with chemical conditioning. At about 100 dry tons/day, chemical conditioning dewatering costs about 25 percent more than heat treatment dewatering.

Table III-C-6

SUMMARY OF NON-COMBUSTION VOLUME REDUCTION

NOTE: TUC = Total Unit Cost in \$/ton (assumes i = 6% for 25 years for amortization costs)
O&M = Operation and Maintenance unit cost in \$/ton * 18-800 tons/day range
CC = Capital Costs in \$/ton per day of capacity ** 50-200 tons/day range
TS = Total Solids COD = Chemical Oxygen Demand TVS - Total Volatile Solids (Organics)

Type	Characteristics	Dewatering Performance	Costs
Gravity Separation - Thickening	Simple, cheap, compact. Used for initial thickening operations. Not applicable to oils and grease.	To 10% TS. "Slow"	Mixed Organic Sludges:* (fresh) \$0.77-1.22 TUC \$0.33-0.45 O&M \$2060-4000 CC Lime:** \$0.34-0.75 TUC \$0.09-0.11 O&M \$1190-2900 CC (Figure III-C-2)
Vacuum Filtration	Generally requires sludge conditioning. Specifically suited for organic and lime sludges. Considerable amount of auxiliary equipment necessary.	Generally to 20-25% TS, 35% possible, perhaps more with heat treatment. Capacity: 20-50 tons/24 hours	Mixed Organic Sludges:* (with chemical conditioning) \$15.90-18.00 TUC \$12.10-12.50 O&M \$17,750-25,000 CC Lime:** \$6.27-7.50 TUC \$1.35 O&M \$22,900-28,500 CC (Figure III-C-4)
Pressure Filtration	Non-continuous operations	To 50% solids	"High labor costs"
Centrifuges	Complex, compact. Suited to organic, lime, toxic and regeneration solids. Chemical conditioning with polymers, grinding for screenings required.	To 15% TS usual, to 30-40% TS possible	Mixed Organic Sludges:* (with chemical conditioning) \$18.80-30 TUC \$8.10-8.70 O&M \$46,700-100,000 CC Lime:** \$20.70-27.20 TUC \$5.50-5.70 O&M \$71,000-91,500 CC (Figure III-C-7)
Air Flotation	Simple, compact. Applicable	To 6-8% TS	Waste Activated Sludges: (to 6-8% TS)

	quired.		$71,000-91,500 CC (Figure III-C-7)
Air Flotation	Simple, compact. Applicable to sludges with specific gravities under 1.05. Suited for oils, grease, light waste and activated sludges.	To 6-8% TS	Waste Activated Sludges: (to 6-8% TS) $1.62-3.68 TUC $1.00-2.15 O&M $1705-7800 CC (6-300 tons/day range) (Figure III-C-9)
Air Drying on Sand Beds	Simplest, cheapest when land is available, requires remote site locations. Prior digestion or heat treatment advisable.	To 40% TS and about half or less of original wet sludge volume	Mixed Organic Sludges:* $7.40-12.25 TUC $0.65-5.50 O&M $31,500 CC (Figure III-C-12)
Heat Drying	Applicable to all solids, but particularly for dried organic or lime sludges when demand present, other methods not feasible.	To 70-90% TS	Generally not economical. Mixed Organic Sludges: TUC: roughly $70/ton ($56-77) O&M: about 67% TUC
Flash Drying	Complex, flexible-can also incinerate. Operates @1100°F Useful when dried sludges are in demand.	To 65% TS with vacuum filtration and paddle mixing alone, to 90% with flash drying. (95% TS at Chicago-Ref. 212)	Essentially the same as heat drying in general.
Heat Treatment Conditioning	Porteous: @300-350°F, 350-390 psig Farrer: @360-380°F Carver-Greenfield: integrated with incineration	Enhances dewatering aids to perhaps 55% TS. Can eliminate need for digestion	Mixed Organic Sludges: $14.70-22 TUC (18-100 range) $5.20-7.30 O&M $44,000-68,500 CC (Figure III-C-14)
Wet Air Oxidation	Operates @300-350°F, 300 psig. A heat treatment process variation	Enhances subsequent dewatering. Reductions: 20-40% TVS, 10-45% raw COD, 13-63% digested COD	See Table III-D-25 "High" capital and O&M costs, fuel costs in particular are higher than with combustion process variations
Chemical Sludge Conditioning	Addition of lime, ferric chloride, alum, chlorine or polymers.	Enhances subsequent dewatering.	Included with unit costs of other volume reduction unit operations.
Digestion	Anaerobic or aerobic. Suited for organic sludges, animal	40-60% reduction in TS, aids dewatering	Mixed Organic Sludges:* $13.72-33.50 TUC

	or heat treatment advisable.		$31,500 CC (Figure III-C-12)
at Drying	Applicable to all solids, but particularly for dried organic or lime sludges when demand present, other methods not feasible.	To 70-90% TS	Generally not economical. Mixed Organic Sludges: TUC: roughly $70/ton ($56-77) O&M: about 67% TUC
sh Drying	Complex, flexible-can also incinerate. Operates @1100°F Useful when dried sludges are in demand.	To 65% TS with vacuum filtration and paddle mixing alone, to 90% with flash drying. (95% TS at Chicago-Ref. 212)	Essentially the same as heat drying in general.
at Treatment onditioning	Porteous:@300-350°F, 350-390 psig Farrer:@360-380°F Carver-Greenfield: integrated with incineration	Enhances dewatering aids to perhaps 55% TS. Can eliminate need for digestion	Mixed Organic Sludges: $14.70-22 TUC (18-100 range) $5.20-7.30 O&M $44,000-68,500 CC (Figure III-C-14)
et Air xidation	Operates @300-350°F, 300 psig. A heat treatment process variation	Enhances subsequent dewatering. Reductions: 20-40% TVS, 10-45% raw COD, 13-63% digested COD	See Table III-D-25 "High" capital and O&M costs, fuel costs in particular are higher than with combustion process variations
hemical udge onditioning	Addition of lime, ferric chloride, alum, chlorine or polymers.	Enhances subsequent dewatering.	Included with unit costs of other volume reduction unit operations.
igestion	Anaerobic or aerobic. Suited for organic sludges, animal and vegetable oils and grease	40-60% reduction in TS, aids dewatering	Mixed Organic Sludges:* $13.72-33.50 TUC $6.85-19.80 O&M $32,600-64,000 CC (Figure III-C-17)
uture rends	Freezing, hydrasieving, irradiation, ultrafiltration, ultrasonics, chemical oxidation with chlorine, screening		

D. HIGH TEMPERATURE VOLUME REDUCTION

D. HIGH TEMPERATURE VOLUME REDUCTION

1 - General

As indicated in the introductory comments to section III-C-1, incineration and other high temperature volume reduction processes constitute a distinct sub-grouping of pre-disposal treatment and volume reduction methods. 1/ Since organic sewage sludge and other wastewater residual solid materials can be processed by incineration, it is important to have a knowledge of some of their basic combustion characteristics. One of the most important is the heat value, expressed in British Thermal Units (BTU) per pound of dry solids. The following table summarizes the various heat values reported in the literature.

Table III-D-1
SUMMARY OF HEAT VALUES FOR VARIOUS RESIDUAL SOLIDS

Material	Typical Heat Values (BTU/lb dry)
Raw Sewage Solids	10,285 (@ 26.0% Ash)
Fine Screenings	8,990 (@ 13.6% Ash)
Grit	4,000 (@ 69.8% Ash)
Grease and Scum	16,750 (@ 11.5% Ash)
Primary Sludge	7,820; 6500-9200 (60-80% Ash)
Activated Sludge	6,540; 5900-8000 (60-80% Ash)
Digested Sludge	5,290 (@ 40.4% Ash); 3500-4000

(Refs. 24 (p.176, 180), 88, 119, 123, 154 (p.248), see Table III-C-5

The mixture of sewage sludge, grit, screenings and scum, as it might be applied to an incinerator, can be assigned a heat value of 10,000 BTU/lb. (Ref. 123). However, it is the volatile to inert material ratio that most significantly affects the heat value. This ratio is, to some extent, controlled by other treatment processes such as mechanical dewatering and sludge digestion. Almost all of the combustibles are present in the sludge as volatiles, and as much as 25-30% of the volatiles can be in the form of grease. The volatile percentage and, therefore, the heat value can vary widely, so incineration equipment must be designed to handle a broad range of heat values.

1/ General References for this Technical Appendix III Chapter include: 6, 9, 15, 24, 25, 33, 39, 41, 47, 82-101, 103-135, 137, 138, 154, 194.

If the ultimate chemical analysis of sludge is known, the Du Long formula can be utilized to yield an approximate heat value (Refs. 119, 123):

$$Q = 14{,}600\ C + 62{,}000\ (H - \frac{O}{8})$$

Where:

Q = BTU/lb dry
C = Amount of carbon expressed in Lb C / Lb dry sludge
H = Amount of hydrogen expressed in Lb H / Lb dry sludge
O = Amount of oxygen expressed in Lb O_2 / Lb dry sludge

The following chemical analysis is offered as being typical for primary sedimentation sludge (Ref. 118):

Table III-D-2
TYPICAL PRIMARY SLUDGE CHEMICAL ANALYSIS

	C (lb)	H (lb)	S (lb)	O_2 (lb)	N_2 (lb)	Ash (lb)
Sludge-1 lb dry:	0.437	.064	.0024	0.34	.024	0.14

If the Du long heat value formula is applied to the above data the resulting value of Q is 7682 ETU/lb. This agrees substantially with the information presented in Table III-D-1.

The heat value presented above represents the fuel value of dry primary sludge. However, the presence of moisture reduces the dry heat value of a particular sludge. Therefore the amount of auxiliary fuel required for combustion increases. It is generally assumed that a moisture content of 70-75% will result in a sludge with sufficient heat value to maintain reaction temperatures once combustion has begun (Refs. 82,87,88,97,114,116,118,123).

The sludge mixture applied to an incinerator, with scum, grit and screenings added, may include a percentage of chemical additives. These chemical are usually added for three reasons:

1) For aid in the thickening operation,
2) For conditioning prior to dewatering on a vacuum filter,
3) For removal of phosphate.

The type of additives used include lime, ferric chloride and certain polymers. These additives offer no special problems with regard to

incineration, although the additives can alter slightly the composition of the residue. Lime added for sludge conditioning, to aid flocculation and dewatering, and for phosphate removal can add as much as 25 to 37 percent to ash lime contents (as CaO); the ash lime content being in the range of 8 to 9 percent without such additions (Ref. 128). Other conditioning chemicals add to the related chemical components of ash residues in lesser amounts.

2 - Air Quality and Stack Emission Standards

The most objectionable and the most prevalent air contaminant in incinerator stack emissions is particulate matter. The presence of particulate matter is most noticeably indicated by the degree of opacity of the stack effluent gas. The opacity, however, does not represent a definitive analysis of the quantity of particulates present. That value must be determined by sampling and calculation, as will be described in later sections.

The standard chosen by the Bay Area Air Pollution Control District for the measurement of the opacity of a gas is the Ringlemann Chart. The Ringlemann Chart is a well established and widely used "measuring stick" for visible emissions. The chart consists of a series of shade diagrams formed by horizontal and vertical black lines on a white background. The shades range from Ringlemann No's. 0, 1, 2, 3, 4, 5 representing 0, 20, 40, 60, 80 and 100 percent opacity, respectively.

The stack effluent is compared to the Ringlemann chart and the Ringlemann number most closely resembling the shade of the gas is recorded. It is this value that is subjected to the stack emission regulations. The following paragraphs briefly summarize the stack emission and standards pertaining to visible emissions. For more detail concerning these particular standards and also the procedures for utilization of the Ringlemann Chart, refer to Section III-D-8.

The present standard requiring that no emission with a Ringlemann value of No. 1 or higher is permitted for more than three minutes during any one hour period from any emission point is subject to minor exceptions. For example, water vapor can cause a degree of opacity. If the presence of uncombined water is the only reason for failure of an emission to meet the limitations of the above standard, that standard shall not apply. Other exceptions to the visible emission standard are presented in Section III-D-8.

The actual quantity of particulate matter contained in a gas stream is also subject to the Bay Area Air Pollution Control District (BAAPCD) regulations. The regulations state that no emission from an incinerator operation capable of burning not more than 100 tons of waste material per day of particulate matter in excess of a concentration of 0.15 grains per standard dry cubic foot of exhaust gas shall be permitted. For the purpose of this standard the measured concentration of particulate matter in the exhaust gas shall be corrected to the concentration of particulate matter in the exhaust gas shall be corrected to the concentration which the same quantity of particulate matter would constitute in the exhaust gas, if it were dry, and contained 6 percent oxygen by volume at standard conditions. The BAAPCD defines standard conditions as: "14.7 lbs/sq in. of atmospheric pressure and a temperature of 60°F." A sample calculation for the correction of measured data is presented in Section III-D-8.

Sulfur Dioxide Emission. Sewage sludge contains sulfur in trace amounts (Ref. 118). In addition, auxiliary fuel may contain sulfur impurities. For these reasons stack emissions are subject to the BAAPCD standards for sulfur dioxide. However, it is not expected that sulfur dioxide emissions will approach presently unacceptable limits due to the incineration of sludge.

The regulations governing SO_2 emissions are divided into two areas. The first concerns the actual concentration of sulfur dioxide in the effluent gas stream, which is not permitted to exceed 300 ppm. The second area involves the ground level air quality. The standard states, briefly, that no emissions that will result in a ground level concentration exceeding 0.5 ppm for three consecutive minutes, or an average concentration of 0. 5 ppm for sixty consecutive minutes, or an average concentration of 0.04 ppm for a 24 hour period will be permitted.

Hydrocarbons and Carbonyls. These contaminants are not to individually exceed a concentration in exhaust gas of 25 ppm. The measured values must be corrected to standard conditions and six percent oxygen by volume.

Objectionable Odors. The emission of objectionable odors is not an area of major concern. The operating temperatures which can be achieved by the available processes are sufficiently high to destroy most odors which may be present.

Oxides of Nitrogen. The operating temperatures of the available sludge incineration processes are not sufficiently high (less than 2000°F) to oxidize the nitrogen present in air. Therefore the pollution threat posed by photo-chemical oxidants is minimal.

3 - Pretreatment

Any process that is chosen for the purpose of sludge disposal pretreatment should encompass one or both of the following objectives. First, it should reduce the volume of the sludge prior to further treatment and disposal by the removal of water. Second, the organic solids which represent a potential pollutant and a considerable nuisance must be stabilized or rendered inert.

The high moisture content of sludge is a deterring factor with respect to high temperature volume reduction. Heating values decrease with increasing moisture content, resulting in an increased auxiliary fuel requirement. It is therefore desirable, prior to high temperature volume reduction, to dewater sludge to the greatest extent effectively and economically permitted by present technology.

A detailed description of sludge dewatering is presented in Section III-C.

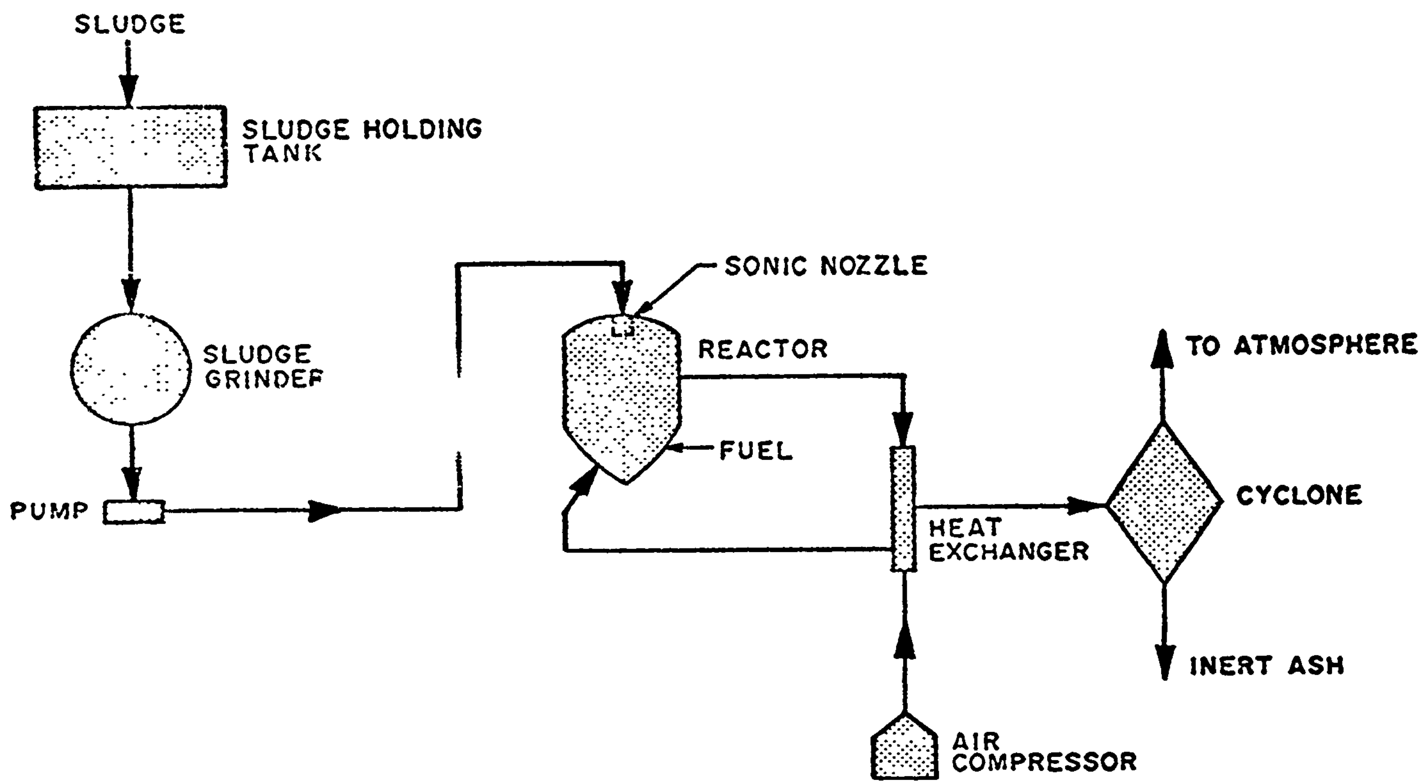
4 - Process Descriptions

The high temperature volume reduction operations most applicable or potentially applicable to wastewater residual sludges and solids are: (1) atomized suspension incineration, (2) wet air oxidation, (3) fluidized bed incineration, (4) multiple-hearth incineration, (5) rotary kiln incineration, and (6) pyrolysis. These are discussed in the following pages and summarized in Section III-D-9 (Table III-D-26).

a. Atomized Suspension Technique

The atomized suspension technique, also called atomized spray technique or thermosonic reactor system, is a process designed for high temperature - low pressure thermal processing of sewage sludges. This process bears a resemblance to spray drying which has been employed in the past for the thermal destruction of organic matter.

The process as indicated on the accompanying flow chart, Figure III-D-1, can be described as follows: sludge is thickened which for efficient operation should be greater than 8 percent but no more than 14 percent total solids. The sludge is then ground to produce particles that can be handled by the sonic nozzle without operating difficulty. The sonic nozzle, which is a unique feature of this process, produces a mist and fine particle spray at the top of the reactor. The atomized particles are then sprayed downward into the reactor. Heat is transferred from



ATOMIZED SPRAY TECHNIQUE

Figure III - D-1

the annulus of the reactor by combustion products passing at high velocities from the lower chambers of the incinerator.

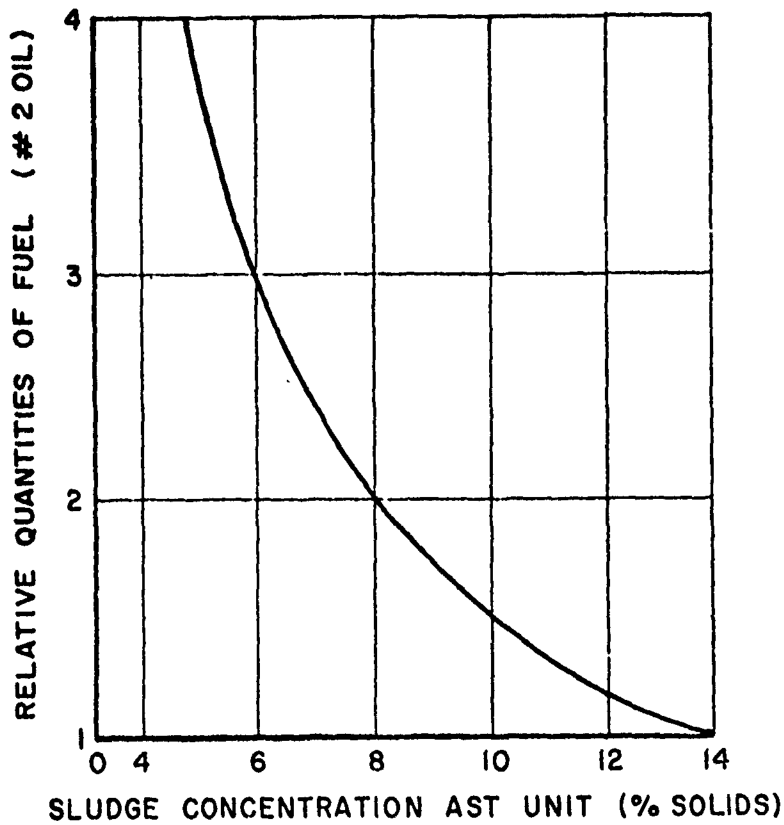
The atomized sludge passes through four zones in the incinerator where the following processes occur: the atomized sludge is heated to approximately 212^{o}F in the preheating zone; evaporation takes place in the next zone while temperatures remain at 212^{o}F; drying of sludge particles also occurs in the evaporation zone and these particles ignite at 600^{o}F in the super-heating zone; combustion occurs in the combustion zone, in which temperatures approach 2000^{o}F. The combustion products (gases and particulates) leave the incinerator via the annulus and exchange heat with the incoming mist. The amount of heat transfer between combustion products and incoming mist is in the range of 6000-10,000 Btu/ft^{2}/hr (Ref. 100). The operating pressures in the reactor are maintained at 30 inches of water.

The combustion products are also passed through a heat exchanger after leaving the incinerator. Incoming air absorbs much of the liberated heat and is then injected into the reactor.

The combustion particulates are removed from the combustion gas stream by use of a cyclone. The gases are then vented to the atmosphere and the ash, which is reported to be inert, can be disposed of by landfill (Ref. 99, 100).

As in most incineration processes auxiliary fuel is required for the atomized spray technique. Figure III-D-2 shows relative fuel quantities as a function of sludge concentration to illustrate these fuel costs and therefore the higher operating costs associated with sludge loadings with total solids content less than 8 percent. It can be expected that auxiliary fuel requirements for this process will be higher than for other high temperature volume reduction processes. This is due to the fact that raw primary sludge, which has the highest heating value of all sludge types, is capable of self-sustaining reactions only at 70-75 percent moisture content; this process works best at 92 percent moisture; its lower working limit is 86 percent moisture.

The reported advantages for this process are (1) versatility of sludge handling, (2) continuous and rapid conversion of raw sludge to innocuous ash, steam and carbon dioxide, (3) small space requirements, (4) close system operations, (5) few, if any, associated nuisance conditions and (6) flexibility in the ability to undertake either drying or complete oxidation (Ref. 154). This process is a new type and little experience with it has been accumulated. It also appears to offer possibilities for the incineration of dilute sludges and in the



(adapted from Fig. 19. VII, Ref. 154)

RELATIVE FUEL COSTS
ATOMIZED SUSPENSION TECHNIQUE UNIT

Figure III-D-2

process eliminate costly dewatering unit operations. As noted previously, however, the unit is less efficient when input total solids concentration are under 8 percent. The indicated disadvantages appear to center on costs which are reported to be somewhat higher than those encountered with current conventional processes. Extrapolations from limited information indicate a current cost picture as shown in Table III-D-3.

Table III-D-3
ATOMIZED SPRAY TECHNIQUE PROCESS COSTS

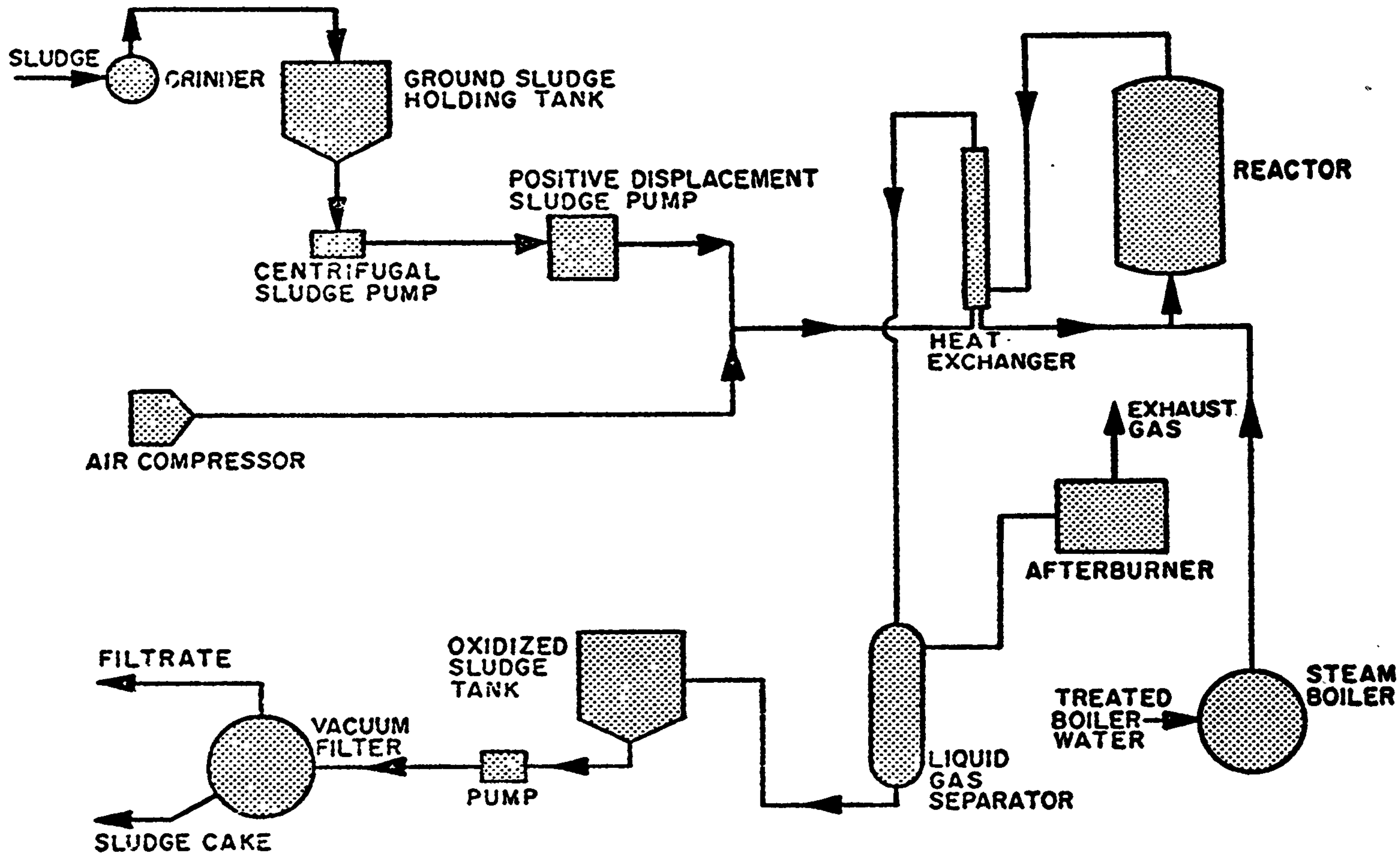
(Based on information in Ref. 154, treatment plant cost index values reported in the Engineering News-Record, June 22, 1972, assumptions of i = 6%, use life = 25 years, CRF = 0.0782)

	@ 6 tons/day	@ 50 tons/day
Capital cost/ton per day of capacity	$165,000	$73,500
Amortized capital cost/ton dry solids	$36	$16
Operation costs/ton dry solids	41	25
Total unit costs/ton dry solids	$77	$41

b. Wet Oxidation

The wet oxidation or Zimmermann process is a method of combustion in which sludge solids are oxidized while the sludge is in a liquid state. The degree of oxidation obtained is a function of four major factors: temperature, pressure, holding time and feed solids concentration (Ref. 108).

The wet oxidation process is presented in flow chart form in Figure III-D-3, and it can be described as follows. Sludge is ground and thickened to roughly three percent solids concentration, then mixed with compressed air. The mixture is passed through a heat exchanger where it absorbs heat from the combustion products of a previous oxidation. The sludge air mixture then enters the reactor where the actual wet combustion takes place. The combustion reactions result in a temperature rise and the generation of heat. Often the heat generated is not sufficient to maintain the desired operating temperatures. In these cases super-heated steam is injected directly into the reactor. As was stated above, this heat is recovered by heat exchange and is utilized to raise the temperature of the incoming sludge-air mixture.



DEWATERING AND SLUDGE OXIDATION

ZIMMERMANN PROCESS

Figure III - D-3

The reactor effluent which consists of a liquid gas mixture then enters a separator. The gases are piped to an afterburner and then vented to the atmosphere. The oxidized sludge is applied to a vacuum filter or centrifuge for dewatering. The filtrate or centrate is usually reprocessed through the sewage treatment works. The literature reports that the liquid portion of the oxidized sludge, though high in five day biochemical oxygen demand (BOD_5), is amenable to biological treatment. The oxidized sludge cake can vary in composition from partially stabilized organics to ash. However, it cannot be considered to be inert. Even the high pressure and temperature wet oxidation processes, designed to achieve maximum BOD_5 reduction, leaves a solid residue with a BOD_5 that may be as high as 1.0 g/l (Refs. 102, 106).

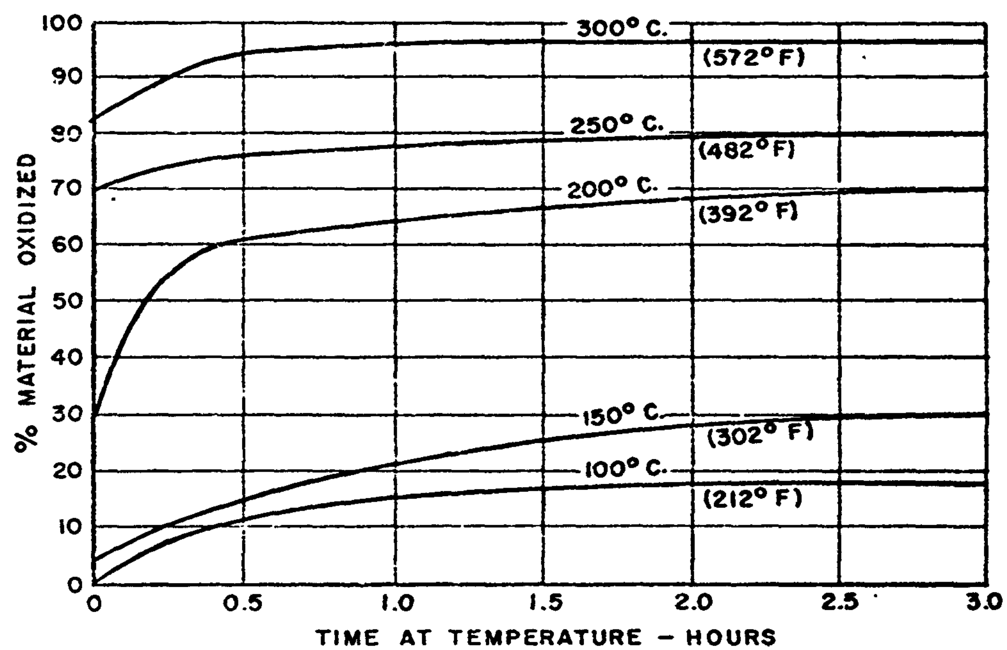
The wet oxidation process can be divided into three categories as indicated in Table III-D-4.

Table III-D-4
WET OXIDATION OPERATING CONDITIONS

Process	Nominal Temperature Range	Nominal Pressure Range	% Volatile Solids Reduction Based on Nominal Detention of 1.5 Hours
Low Pressure, Low Temperature	300-350°F	300 psig	20-40%
High Pressure, Intermediate Temperature	350-500°F	800 psig	60-80%
High Pressure, High Temperature	500-550°F	1200-1800 psig	85-90%

(From Ref. 103)

As can be interpreted from a review of Table III-D-3, and as stated previously, temperature is one of the most significant process parameters. Figure III-D-4 presents a more detailed picture of the relationship between temperature, holding time and the degree of oxidation.



TEMPERATURE-REACTION SPEED RELATIONSHIP: WET OXIDATION

Figure III-D-4
(Ref. 106, Fig. 1)

The characteristics of sludge may be expressed either physically or chemically. Physical characteristics include moisture, density, color, odor, texture, fluidity and plasticity. Table III-B-1 presents the chemical characteristics of various typical organic sludges.

7 - Toxic Solids

Toxic solids are not presently being removed separately from wastewaters. New waste control regulations emphasize required removal of toxic solids at the source. Minor concentrations of trace toxic materials are removed with organic sludges, or lime sludges where that process is used. Toxic solids would typically include phenols and heavy metals, 80 percent and 40 percent respectively being removable with the organic sludges.

8 - Regeneration Solids

Regeneration solids are the finely divided materials removed from tertiary treatment effluent filters and carbon absorption columns in the backwashing operation. The finely divided organic and inorganic solids removed from effluent filters contain some lippoids. These backwashings are normally recycled back into the plant inflow and subsequently the bulk of them are removed with the organic sludges. Under anticipated techniques they will present no special problems.

Since combustion is an oxidation reaction, an adequate supply of oxygen must be present to assure combustion of the organic matter. It is important, therefore, to have available, for design and operation purposes, the oxygen and air requirements for the combustion of process materials. Table III-D-5 presents the air and oxygen requirements for the combustion of materials typical of these processed by wet oxidation.

Table III-D-5
HEAT CHARACTERISTICS IN OXIDATION

Material	Heat value (Btu/lb)	O_2 used lb/lb material	Air used lb/lb material	Heat in terms of air use (Btu/lb. air)
Carbon	14,093	2.66	11.53	1,220
Fuel Oil	19,376	3.26	14.0	1,380
Waste Solids	7,900	1.32	5.7	1,385
Semi-chemical Solids	5,812	0.96	4.13	1,410
Sewage Sludge Primary	7,820	1.33	5.75	1,365
Sewage Sludge Activated	6,540	1.19	5.14	1,270

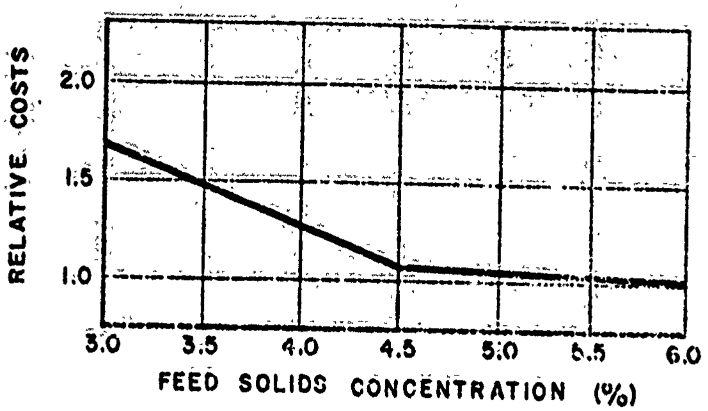
(Ref. 106, Table 1)

The description of the wet oxidation process presented earlier in the text states that the sludge is oxidized while in liquid form. The operating temperatures, however, are in excess of 212°F. It is therefore required that the reactor vessel be pressurized during combustion stages. The required pressure ranges corresponding to low, intermediate and high temperature wet oxidation (from Table III-D-4) are as follows:

Low Pressure, Low Temperature	300 psig
High Pressure, Intermediate Temp.	800 psig
High Pressure, High Temperature	1200-1800 psig

The more costly dewatering stages such as vacuum filtration or centrifugation required by the incineration process are not needed prior to wet oxidation. It appears, however, that cost savings can be realized if sludge is thickened to 6 percent solids (Ref. 105).

Figure III-D-5 illustrates the relationship between system cost (amortization and operation) and fuel solids concentration for the wet oxidation units in Chicago, Illinois.



FEED SOLIDS CONCENTRATIONS - COST RELATIONS: WET AIR OXIDATION AT CHICAGO

Figure III-D-5

(Adapted from Fig. 2, Ref. 105)

It can be determined from this figure that a considerable saving could be realized if thickening operations were allowed to proceed to an end product consisting of 6 percent solids. The specific unit cost cited for the Chicago example at 6 percent feed solids concentration was about $23/ton in 1965 (Ref. 105). This includes amortization at 4 percent interest together with operation and maintenance costs. No use life basis or breakdown between amortization and operation and maintenance was given. The maximum capacity of the unit from which the values were developed was 210 tons per day.

Process Operating Performance. The wet oxidation process can be divided into two categories: low temperature and high temperature oxidation. The primary purposes of the two process variations are quite different. Low pressure and temperature oxidation, which occurs at temperatures of 300°-350°F and 300 psig, is intended for heat treatment. Its primary function is to condition the sludge to facilitate dewatering by vacuum filtration or centrifugation. There is an accompanying reduction in volatile matter, usually about 30 percent. However, the process effluent is still a potent pollutant and requires further treatment prior to disposal.

A useful measure of filterability is the filtration resistance. A theoretical treatment is presented by McCahl and Eckenfelder (Ref. 129). The filtration resistance is usually expressed in units of sec^2/g. Table III-D-6 indicates the affect on "dewaterability" of low temperature wet oxidation.

Table III-D-6
LOW TEMPERATURE WET OXIDATION RESULTS

		Value of Sludge Oxidized at Given Temperature			
		Unoxidized	350°F	357°F	392°F
Raw Primary	(1) COD reduction	0	19	28	45
	(2) Filtration resistance $sec^2/g \times 10^7$	967	26	3	5
Digested	(1) COD Reduction	0	16	23	49
	(2) Filtration Resistance	824	21	13	9
Raw Activated	(1) COD Reduction	0	10	19	42
	(2) Filtration Resistance	18,700	741	14	14
Digested (act & prim)	(1) COD Reduction	0	13	40	63
	(2) Filtration Resistance	2,170	40	6	7

(Ref. 39)

The cost of low pressure and temperature oxidation must be compared to the cost of the addition of conditioning chemicals before any selection requiring a conditioning technique is made. Direct cost comparisons are not readily available. Such comparisons should not however be overlooked in an economic analysis. It would appear that capital costs are about the same as for high pressure oxidation. Several elements of operating costs, such as power costs, also appear to be equivalent. Fuel costs, however, appear to be about four times that experienced with high temperature and high pressure oxidation (Ref. 154).

<u>High Pressure Oxidation.</u> High pressure wet oxidation which takes place in the operating ranges of 350°-550°F and 800-1800 psig. It is employed when volume reduction of the sludge and stabilization of the organic matter is required. The wet oxidation process performance, in terms of volatile solids reduction, is outlined in Table III-D-7, and Table III-D-8 gives actual operating data from a high pressure and temperature test run (operating temperature 550°F).

Table III-D-7
WET OXIDATION PROCESS PERFORMANCE

	Operating Temperatures	Pressure	% Volatiles Reduction based on 1.5 hour Detention
Low Pressure	300-350°F	300 psig	20-40%
High Pressure	350-550°F	800-1800 psig	85-90%

(From Table III-D-3)

Table III-D-8
OPERATING DATA - HIGH TEMPERATURE WET OXIDATION (550°F)

Pressure (psig)	1525	1820
Influent		
(a) COD g/l	44.5	49.8
(b) % volatile	2.16	2.3
(c) % solids	3.3	3.5
Effluent		
(a) COD g/l	9.3	8.1
(b) % volatile	0.24	0.17
(c) % solids	1.14	0.92
Reduction		
(a) COD Reduction (%)	80	85
(b) Volatile Reduction (%)	88	92
(c) Solids Reduction (%)	65	74

(Ref. 106)

The high temperature wet oxidation process can significantly reduce the 5-day biochemical oxygen demand (BOD_5) of the influent sludge; however, the effluent must undergo additional treatment prior to final disposal. The literature indicates, though only in general terms, that this effluent is amenable to biological treatment and can be recycled to the head of the treatment works without reducing the efficiency of the sewage treatment process (Ref. 106). It is possible to separate the effluent into liquid and solid portions by gravity settling, vacuum filtration or centrifugation. For these three methods of separation the major percentage of the BOD_5 would remain in the liquid portion, which should be recycled for further treatment. The separated solids which are a type of ash are still high in BOD_5. However, they could be applied to a land spreading operation for final disposal.

Table III-D-9 presents wet oxidation process costs.

Table III-D-9

HIGH TEMPERATURE WET OXIDATION PROCESS COSTS

1. Based on all ancillary unit operations shown in Figure III-D-3 rated for about 60 tons/day dry sludge solids. Assumed an interest rate of 6 percent and an estimated use life of 25 years for computing amortized capital cost, (CRF = 0.0782). Based on direct manufacturer's information; assume January 1972 cost datum.

Capital Cost:	$140,000 /ton/day of capacity
Amortized Capital Cost:	$ 30.00/ton
Operation & Maintenance Cost:	$120.00/ton
Total Unit Cost:	$150.00/ton

Typical Breakdown of Operation and Maintenance Costs:

Power	18%	Labor	41%
Fuel	10%	Chemicals	24%
Maintenance	7%	(Ref. 135)	

2. Miscellaneous Reported Cost Values:

a. $23/ton total unit cost cites (Ref. 105) in 1965 for a unit with a maximum capacity of 210 tons per day. Figure represented most efficient operation at 6% feed solids concentration. Rough updating to 1972 San Francisco using ENR index produces a value of about $36/ton.

b. $42/ton reported (Ref. 216) as current approximate and general value.

c. Extrapolation to 1972 from a Rye, NY 2.5 ton/day facility (Ref. 107).

Capital Cost:	$149,000/ton/day capacity
Amortized CC:	$ 31.90 (6%, 25 years)
O&M Unit Cost:	$ 38.00 (51% power, 13% chemicals, 13% water, 23% labor)
Total Unit Cost:	$ 69.90

d. Extrapolation to 1972 from a Wheeling, W. Va. 5.6 ton/day facility (Ref. 154).

Capital Cost:	$79,300/ton/day capacity
Amortized CC:	$17.00 (6%, 25 years)
O&M Unit Cost:	$31.30 (31% power, 21% chemicals, 35% labor, 8% fuel, 5% maintenance)
Total Unit Cost:	$48.30

c. Fluidized Bed Incineration

The fluidized-bed incineration technique presently available for application to sludge disposal problems is similar to that used in industrial processing for many years. This process has been previously employed in the chemical, metallurgical, nonmetallic, food and pharmaceutical industries for drying, roasting, calcining and other heat treatment operations.

The fluidized-bed incinerator utilizes the principle that beds of solid particles can be set in fluid motion by passing a stream of gas, under controlled conditions, up through the solid particles. The gas stream forces a passage between the particles, setting the particles in homogeneous motion and causing the mass to take on fluid character.

The fluidized-bed incineration process is illustrated by a flow chart in Figure III-D-6. The following is offered as a brief description of the process.

Thickened sludge is fed to a vacuum filter or centrifuge where it is dewatered to approximately 75-80% moisture content. The sludge cake is then ground up and fed to the reactor vessel. The reactor containing the fluidized-bed acts as a large heat reservoir where rapid mixing can take place. The sludge particles are usually sprayed from the top of the reactor and are kept suspended in the moving stream of gases. The fluidized sand bed is capable of retaining the sludge particles until oxidation can occur (Ref. 122).

The combustion of the organic material must occur very quickly and in a small operating volume. Therefore the turbulent mixing induced by the air stream is crucial to the efficient operation of the process. Heat liberated from combustion products during heat exchange stages is employed to increase the temperature of the influent air stream. These combustion products, including gas and particulate matter, are carried out of the reactor by the upward air flow. Subsequent to heat exchange the combustion products are treated by wet scrubbers. The ash is separated from the waste slurry by a centrifuge or, in some instances, by gravity.

Auxiliary fuel, usually #2 fuel oil or natural gas, is required to bring the reactor and sand bed up to operating temperatures (1500°F). If primary sludge, dewatered to 75% moisture, is burned the heat generated in most cases is sufficient to maintain operating conditions. The processing of secondary or digested sludge, however, requires auxiliary fuel to maintain desired temperatures. Seventy-five percent moisture

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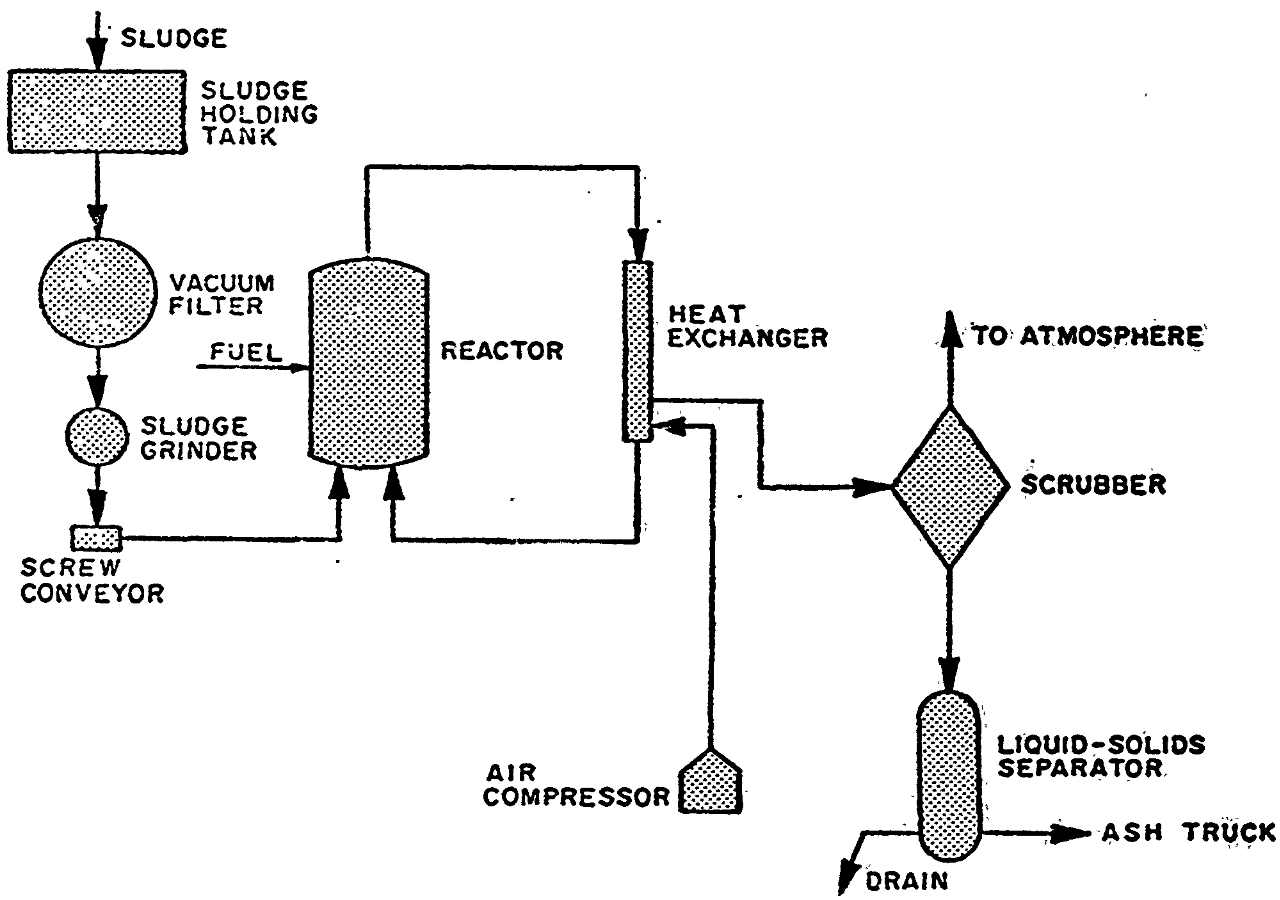


FLUIDIZED BED INCINERATION PROCESS

Figure III - D-6

content is the maximum practical limit recommended by the literature with respect to the economics of the use of auxiliary fuel. Considerable savings, however, can be realized if the moisture content is reduced an additional five percent which is verified by the literature as a practically obtainable value (Refs. 116, 119, 154). In one case (Ref. 154, Fig. 19.IV), auxiliary fuel costs reportedly went from \$2.56/ton dry solids with a 25% solids sludge down to \$0.92/ton dry solids with a 30% solids sludge, a reduction of 64%. This assumes an initial sludge volatile solids content of 75%, sludge heat value of 10,000 BTU/pound volatile solids, gas exit temperature of 1500°F, excess air at 20%, the use of natural gas as the auxiliary fuel with a heat value rating of 1000 BTU/cubic foot and costing \$0.40 per 1000 cubic feet. Note, this cost has not been updated.

In any incineration process an adequate supply of oxygen is essential to assure combustion. It is usual practice to add quantities of air to combustion chambers to assure that the quantity of available oxygen exceeds the stoichiometric requirements for oxidation. This extra quantity of air is referred to as excess air and for the fluidized bed process utilizing natural gas as auxiliary fuel, a value of 20% excess air has been found to be satisfactory (Refs. 113,115,117,154). In addition to aiding combustion, the cooling effect of the excess air serves to prevent operating temperatures from increasing to undesirable values.

Fluidized-bed incinerators can adequately handle loading rates of 13-21 lb/hr per square foot of plan area (Ref. 113). This process is particularly suited for sludges with high grease and oil content (Ref. 113).

<u>Residue</u>. The majority of the combustion solids are carried from the reactor by the upward flowing air stream. However, combustion solids that are comparable in size, shape and weight to sand particles will remain in the bed. These solids will eventually accumulate and can be removed by overflow mechanisms.

Fluidized-bed incineration is a high temperature volume reduction method and not an ultimate disposal process. Therefore the process residue and exhaust gases must be handled, treated and disposed of.

The reactor exhaust gases which carry combustion gases, combustion solids and sand are processed by wet scrubbers. Due to the high gas temperatures and turbulence required for efficient operation, the exhaust gas velocity is usually capable of carrying a considerable amount of particulates from the reactor (Ref. 95). The loading on the

scrubbers is therefore quite heavy and the removal efficiency decreases. The following table illustrates typical exhaust gas composition before and after scrubbing.

Table III-D-10
FLUIDIZED BED INCINERATOR:
TYPICAL EXHAUST GAS COMPOSITION
BEFORE AND AFTER SCRUBBING

	Particulate*	SO_2(ppm)	CO_2(%)	H_2O (%)
Without Scrubber	2.53	27.0	8.0	10.3
With Scrubber	.05	14.0	8.0	15
Allowable (APCD)	0.15	300	---	---

(Ref. 118) *(grains/Std. Cu. Ft.)

As can be deduced from the above table the fluidized bed incinerator would most likely violate stack emission standards for particulate matter without the use of wet scrubbers. This is due to the fact that, with this type of incinerator, most of the ash residue is in the particulate state, i.e., suspended in the exhaust gas stream.

The particulate matter removed by scrubbers must be separated from the liquid-solid mixture. This is usually accomplished by the use of centrifuges. The ash is biologically inert and has some value as a fertilizer. The centrate or liquid portion is usually returned to the head of the sewage treatment works.

The weight reduction which can be achieved by a fluidized-bed unit is in the range of 85-90% of the original sludge cake weight. The percent total solids reduction is about 89 percent where the total volatile solids content was 90 percent. This indicates that ash residue produced is effectively about 110 percent of the ash content of the feed sludge, this reflecting combustion efficiency and incompletely volatized chemical conditioners and auxiliary fuels.

The following table is a partial chemical analysis of a typical fluidized bed ash.

Table III-D-11
TYPICAL FLUIDIZED-BED ASH

Material	Percent
SiO	20
CaO	15
Al_2O	5.3
Fe_2O_3	2.7
Na_2O	1.4
K_2O	1.4
PbO	.053
MnO	.039

(Ref. 123)

Figure III-D-7 presents costs for the fluidized-bed incineration process.

Evaluation.

Disadvantages.

1) The annual cost of fluidized-bed incinerators exceeds by a significant amount all other disposal methods.

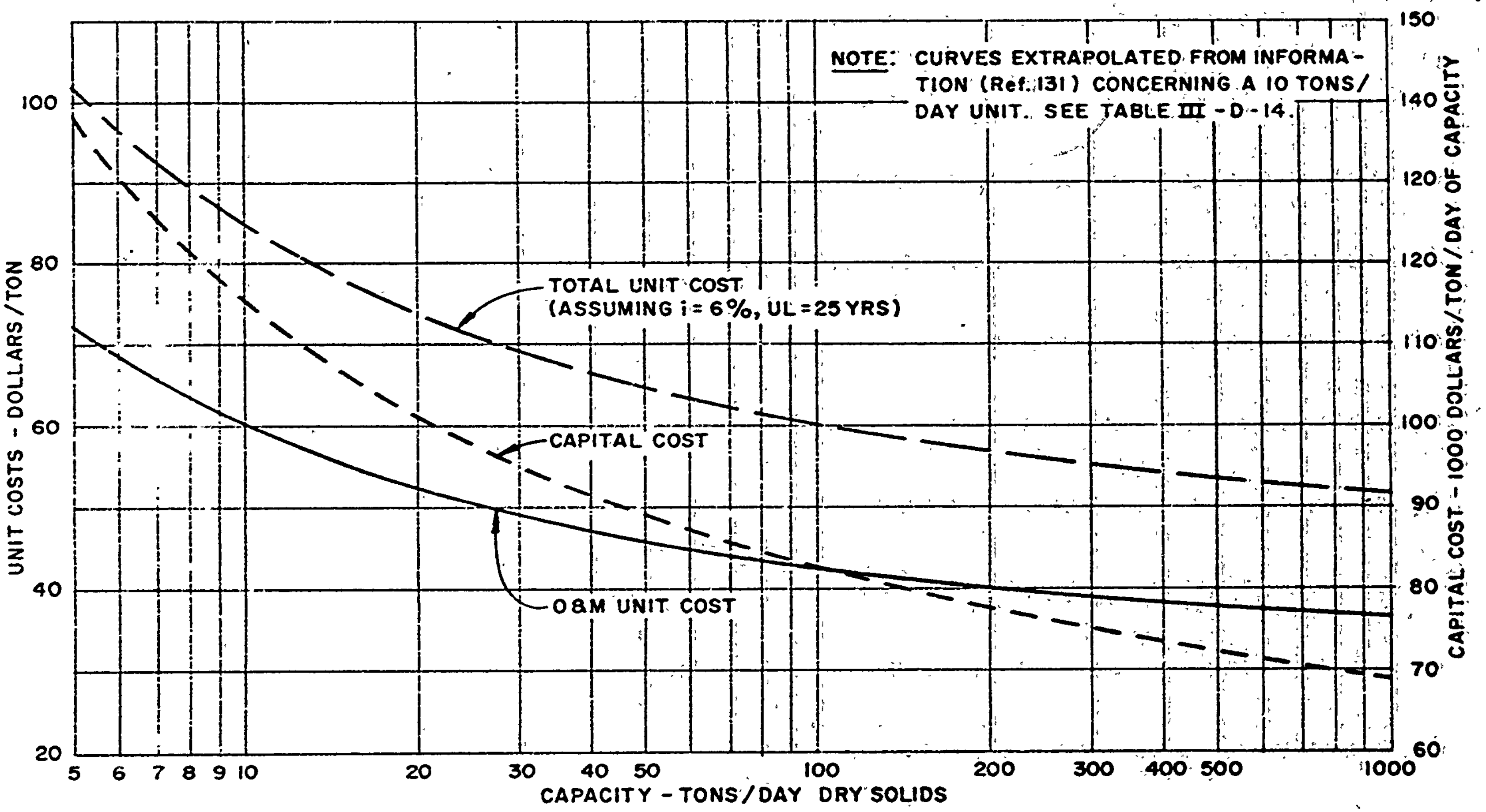
2) There is doubt regarding the soundness of the bed structural design to overcome high temperature stresses (Ref. 131).

3) The air pre-heater is subject to severe corrosion from particulate matter suspended in exhaust gases (Ref. 131).

Advantages

1) Absence of moving parts in reactor reduces operating difficulties.

2) The sand bed is capable of retaining large quantities of heat, thereby facilitating shut-down and start-up operations.



FLUIDIZED - BED INCINERATION PROCESS COST CURVES

(JANUARY 1972 ADJUSTED)

Figure III - D - 7

d. Multiple-Hearth Furnace

The multiple-hearth furnace is the process most generally used for the high temperature volume reduction of sludge. There are more than 175 applications of the multiple-hearth technique in the United States. Multiple-hearth units have been particularly favored in large cities where land requirements for alternate sludge disposal methods are prohibitive (Ref. 84).

The following is offered as a brief description of the multiple-hearth system (Ref. 87). The multiple-hearth furnace is a cylindrical, refractory lined, steel shell containing a series of horizontal refractory hearths located one above the other. These hearths have alternate in-feed and out-feed directions and cause the sludge to move completely across each hearth as it drops from one level to another. These hearths in effect comprise a multi-chamber structure and permit the hot combustion gases to flow past the sludge cake during all stages of drying and incineration. For complete combustion, constant mixing of the sludge cake must occur. This mixing is provided by a motor driven, revolving, insulated central shaft to which is attached radial arms referred to as "rabble arms." Attached to these arms are "rabble" teeth, similar to the plow of a circular clarifier, which move the material across the hearth to the peripheral or central openings through which they crop to the next hearth. Cooling for the rabble arms and central shaft is provided by air which is introduced into a housing at the bottom of the central shaft.

The multiple-hearth furnace is divided into three operating zones. The drying zone is where a major portion of the free moisture is evaporated and consists of the upper hearths. The sludge solids are incinerated at temperatures ranging from 1400°F to 1600°F in the combustion zone. The third zone, the cooling zone, consists of the lowest hearths and serves to cool the ash prior to its discharge into the ash quenching facilities or ash hopper.

The hot gases from the combustion zone liberate heat as they pass the cold sludge at the inflow point. This heat serves to evaporate a significant percentage of the sludge cake moisture. As the sludge particles are rabbled across the hearth they are constantly agitated by the rabble teeth and are reduced to small particle size. This rabbling insures that the maximum sludge surface is exposed to the passing hot furnace gases. These hot exhaust gases are passed through wet scrubbers before being emitted to the atmosphere.

The two exhibits which follow illustrate the various aspects of the multiple-hearth incineration technique. The first flow-chart, Figure III-D-8, depicts the components required to dewater the sludge prior to combustion in a multiple-hearth furnace. The second, Figure III-D-9, shows the incorporation of a multiple-hearth unit into a sewage treatment plant in Cleveland, Ohio. Both flow-charts emphasize the importance of dewatering sludge before incineration. The main purpose of dewatering is to reduce the auxiliary fuel requirements. It is not necessary, however, to dewater below 70 percent moisture content, since at this value filter cake is normally autocombustible after combustion is initiated (Ref. 131-33).

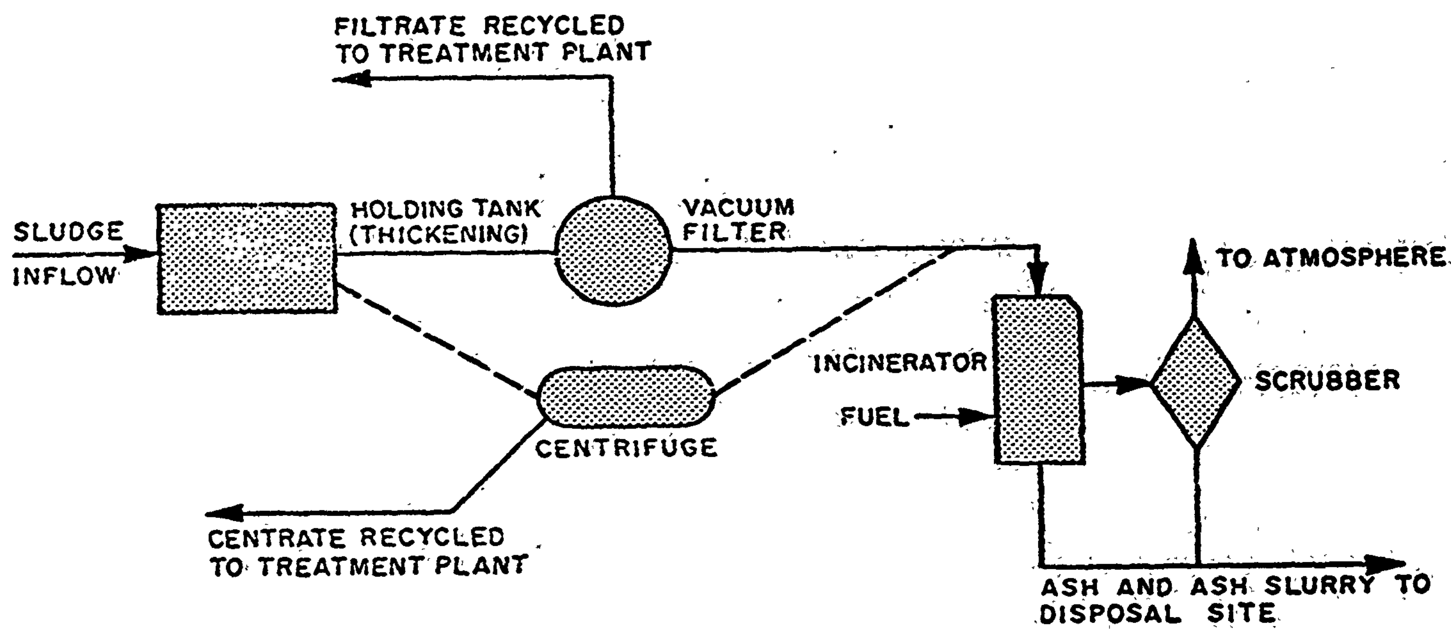
The multiple-hearth furnace is equipped with auxiliary fuel burners at each hearth level. These burners use No. 2 fuel oil and can be adjusted to maintain furnace temperatures as influent sludge compositions change. However, response of the furnace operating temperature to burner adjustment is slow. Instrumentation does not allow for prompt detection of changes in furnace temperature, and, in addition, the multiple-hearth can be upset by varying sludge characteristics. The multiple-hearth unit is designed to function with exit gas temperatures (hearth #1) of 800°F. Taking this as a control point, Figure III-D-10 shows hearth operating temperature ranges over a 24 hour period.

It can be seen that temperatures vary during operation by more than 100 percent. The present control systems of auxiliary burners and excess air flows have been unsuccessful in maintaining uniform operating temperatures (Ref. 131) as is illustrated in Figure III-D-10. Excess air requirement for a multiple-hearth unit is a minimum of 100 percent (Ref. 100).

<u>Residue Handling</u>. Burned material is handled either hydraulically, mechanically or pneumatically, as it leaves the multiple-hearth furnace.

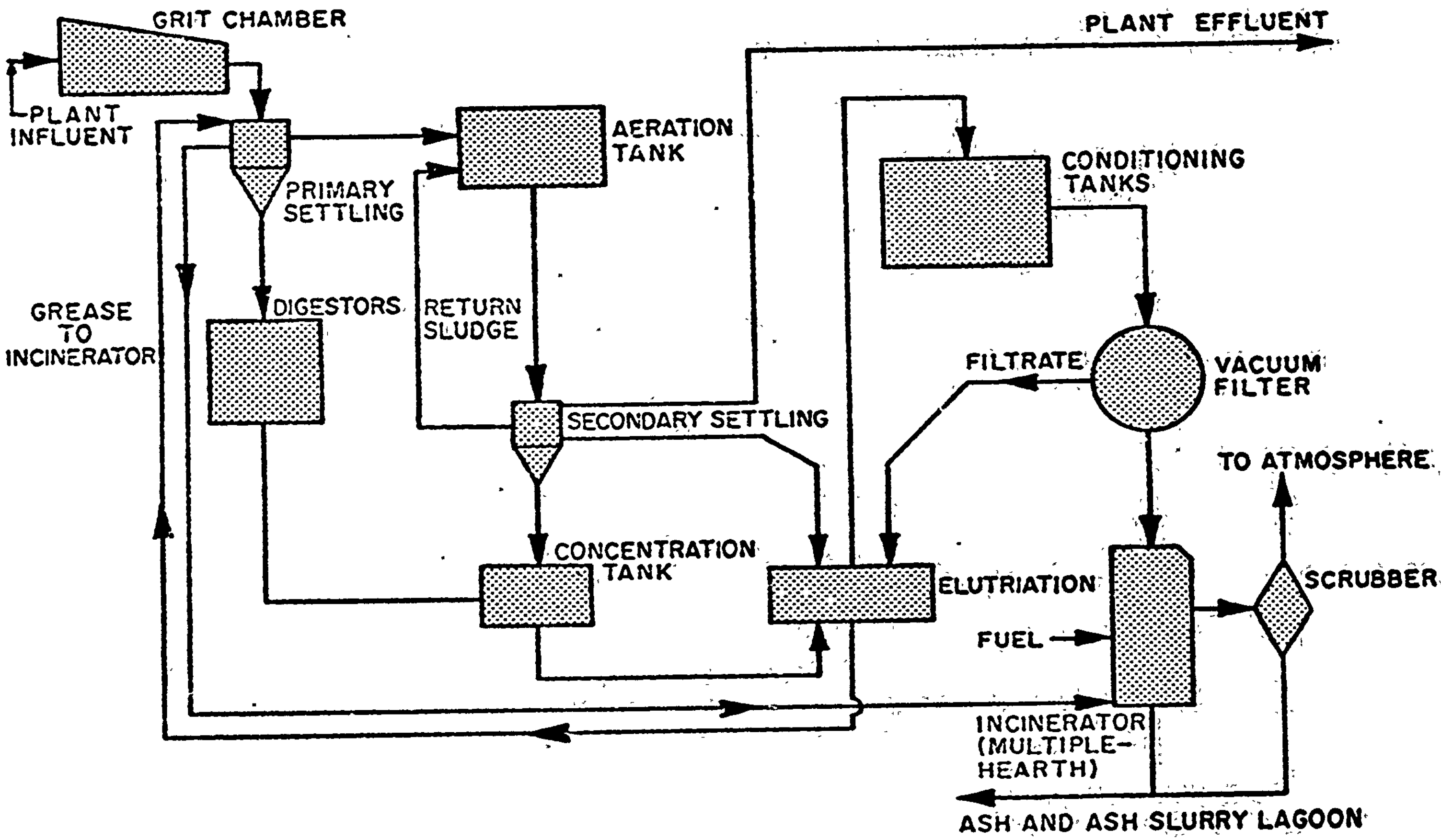
In the hydraulic method the ash falls into an ash tank, located beneath the furnace, where it is mixed with water from the scrubbers. After thorough agitation it is pumped as an ash slurry to a lagoon. This ash slurry dewaters quite rapidly and the resultant bed of material is sterile, inert and free of obnoxious odors and putrescrible matter. After filling of the lagoons, which may take years in some cases, the material is excavated and can be used for fill material in public works projects or general landfill.

In the mechanical method of disposal, the ash is conveyed by means of a water-cooled screw conveyor to a bucket elevator which transports the cooled ash to a storage tank prior to ultimate disposal



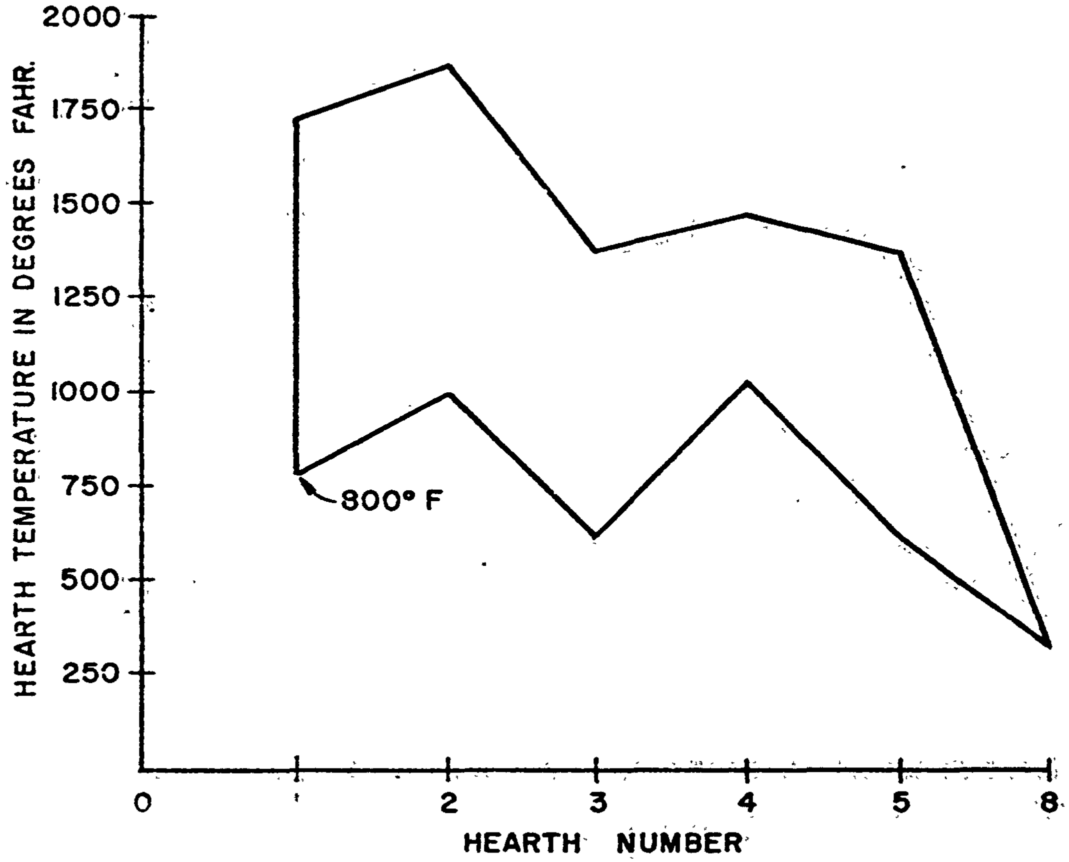
CONVENTIONAL SLUDGE INCINERATION

Figure III -D-8



SLUDGE INCINERATION INCORPORATED INTO A SEWAGE TREATMENT PROCESS

Figure III - D-9



MULTIPLE-HEARTH INCINERATOR TEMPERATURES DURING A 24-HOUR PERIOD

Figure III-D-10
(Ref. 131)

in a fill area. This method of residue handling is often plagued by dust accumulations which can hamper operations.

The pneumatic method of ash disposal utilizes either a vacuum system or a pressure system for transporting the ash material from the furnace via a cyclone separator to a storage hopper from which it goes into a truck body for disposal to a fill area.

In estimating the quantities of ash to be expected from a multiple-hearth unit (Ref. 87), a sludge cake of 75 percent moisture content and a furnace feed of approximately 1000 pounds per hour of dry solids can be assumed. This will result in approximately 400 pounds of ash per hour or about a 90 percent reduction of the incoming sludge cake weight. This assumes an initial or raw total volatile solids (TVS) content of 70 percent and the use of conditioning chemicals amounting to 10 percent of the total wet mass. From this it is estimated that 1.33 pounds of ash residue will be produced per pound of raw TVS, this reflecting combustion efficiency and the volatility of conditioning chemicals and auxiliary fuels. Scrubbing of stack gases should reduce the ash residue going out the stack as particulate matter to 2 percent or less of the total ash residue.

Table III-D-12 presents a partial ash analysis for a typical multiple-hearth installation.

Table III-D-12
TYPICAL MULTIPLE-HEARTH INCINERATOR:
PARTIAL ASH ANALYSIS

Material	Composition %
SiO_2	24.9
Al_2O_3	13.5
Fe_2O_3	10.8
CaO	33.4
Na_2O	0.26
K_2O	0.12
P_2O_5	9.9

(Ref. 128)

Stack Emissions. As can be expected from any incineration operation, the exhaust gases will contain considerable amounts of particulate matter and other gaseous contaminants. The exhaust gases from the multiple-hearth furnace are therefore scrubbed before discharge to the atmosphere. Table III-D-13 summarizes the results of stack tests taken on multiple-hearth units in San Mateo and South Lake Tahoe, California.

Table III-D-13
SUMMARY OF STACK TESTS ON MULTIPLE-HEARTH UNITS

	At San Mateo, Ca.		At South Lake Tahoe, Ca.	
Contaminant	Concentration	Allowable	Concentation	Allowable
Hydrocarbons	2.2ppm	25ppm	28ppm	50ppm
Carbonyls	7.6ppm	25ppm	7.4ppm	50ppm
Particulates	.021 gr/SDCF*	0.15 gr/SDCF*	.01 gr/SDCF*	0.20 gr/SDCF*
Ringlemann	Steam plume	1	0-3/4	1

*Standard Dry Cubic Foot of Stack Gas Corrected to 6% Oxygen and Auxiliary Fuel Deleted.

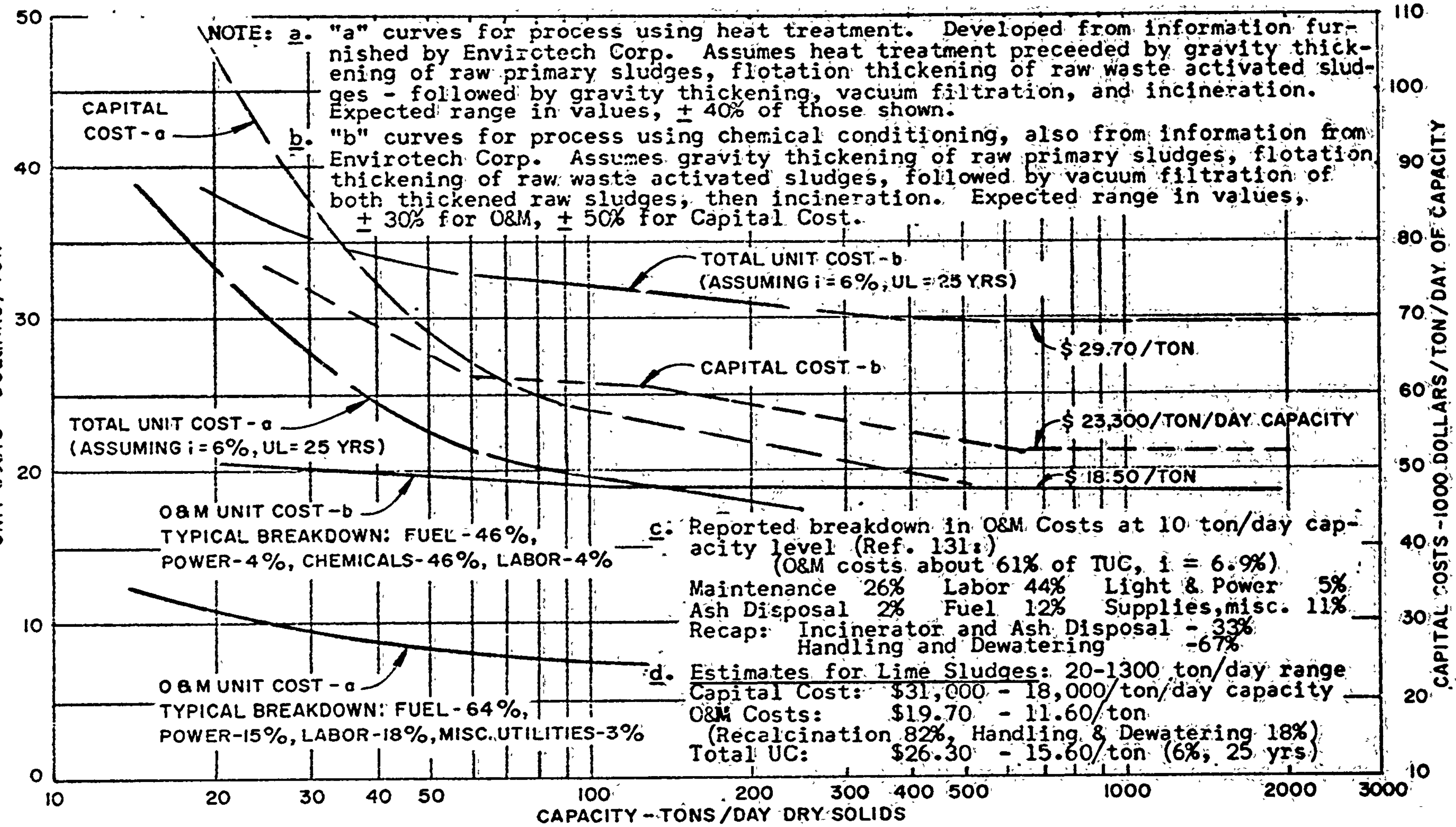
(Ref. 132)

These tables demonstrate the compliance of the multiple-hearth units with the particular air pollution control standards.

Figure III-D-11 presents multiple-hearth process costs.

e. Rotary Kiln

The rotary kiln has the ability to handle waste materials ranging from sewage sludge to bulky refuse. Traditionally the process includes only one kiln, in which drying and incineration of the waste material occur. However, the process illustrated in Figure III-D-12 separates the drying and burning operations into separate kilns. It is this two kiln operation that is used in the high temperature volume reduction of sludge, although at what appears to be significantly higher costs.



(Ref. 29, 131, 135)

MULTIPLE-HEARTH INCINERATION PROCESS COST CURVES

(JANUARY 1972 ADJUSTED)

Figure III-D-11

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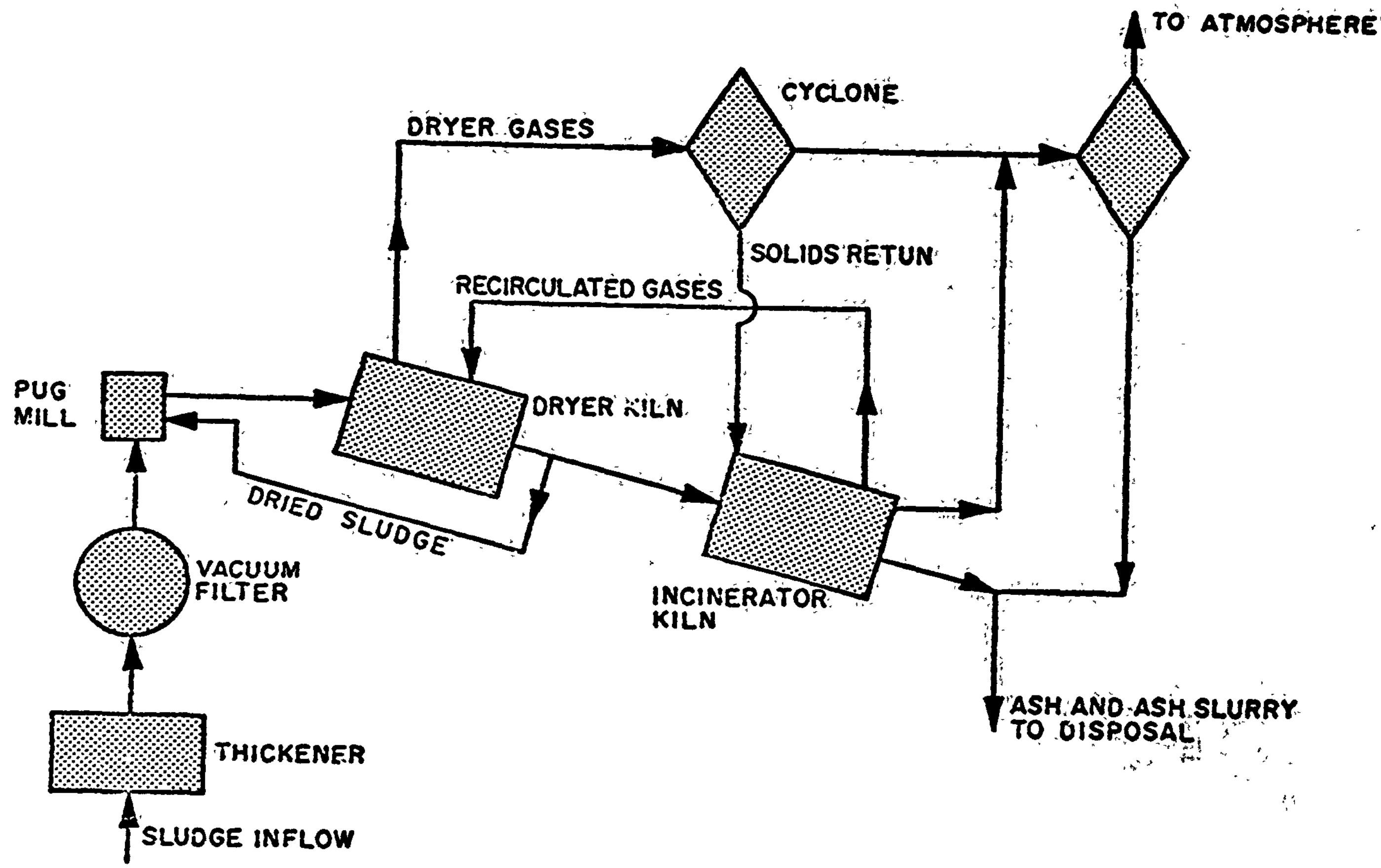


ROTARY KILN

Figure III - D-12

The rotary kiln is a slow rotating cylindrical furnace where the material to be processed is continuously agitated by baffles as they move forward in the kiln. The first kiln, the dryer kiln, dries the wet cake using hot flue gases from the second kiln, the incinerator kiln. The second kiln incinerates the dried cake.

The rotary kiln process requires auxiliary fuel to aid in maintaining operating temperatures sufficient to permit complete combustion of sludge solids. The most common auxiliary fuel is oil. Refuse, however, could be burned along with the sludge and supply a portion of this required auxiliary fuel.

Rotary kiln incineration is preceded by mechanical dewatering, therefore the solids concentration is approximately 20-25 percent upon entering the dryer kiln.

The hot flue gases enter the dryer at about 1100°F. Most of the heat is liberated, resulting in an exit temperature of 250°F. The incinerator kiln operates at temperatures ranging from 1600° to 2000°F with the aid of auxiliary fuel burners. It is desirable to route the exhaust gases from the dryer kiln through the incinerator kiln or possibly through an afterburner to destroy odors.

The dried sludge is in pellet form which facilitates handling during incineration stages. A percentage of this dried sludge is always recirculated and mixed with incoming sludge to assist the drying process. The independingly controlled drying and incinerating operations are the most significant advantages of the rotary kiln (Ref. 131). This independent temperature control allows quick response of the system to varying moisture contents and heat values of the incoming sludge and therefore no major deterioration in process operation results.

One disadvantage is that rotary kiln operations are often plagued with excessive smoking problems and require wet scrubbers or the equivalent to minimize air pollution (Ref. 84).

Table III-D-14 presents developed rotary kiln process costs.

Table III-D-14

ROTARY KILN PROCESS COSTS

(Based on all ancillary unit operations shown in Figures III-D-6,8 and 12 for sludge thickening, dewatering and incineration systems with rated capacity of 5,10 and 500 tons/day dry sludge solids. Assume an interest rate of 6 percent and an estimated use life of 25 years for computing amortized capital costs - CRP = 0.0782)

	@ 5 Tons/day	@ 10 Tons/day	@ 500 Tons/day
Rotary Kiln			
Capital Cost: $/ton/day capacity	$108,000	$90,000	$56,800
Amortized Capital Cost	$23.10/ton	$19.30/ton	$12.20/ton
Oper. & Main. Cost	$40.20	$33.50	$21.10
Total Unit Cost	$63.30/ton	$52.80/ton	$33.50/ton
Fluidized-Bed			
Capital Cost:	$138,000	$115,000	$72,600
Amortized Capital Cost	$29.70/ton	$24.60/ton	$15.50/ton
Oper. & Main. Cost	$72.00	$60.00	$37.90
Total Unit Cost	$101.70/ton	$84.60/ton	$53.40/ton
Multiple-Hearth			
Capital Cost:	$132,000	$110,000	$69,500
Amortized Capital Cost	$28.20/ton	$23.50/ton	$14.80/ton
Oper. & Main. Cost	$44.40	$37.00	$23.40
Total Unit Cost	$72.60	$60.50	$38.20

Typical Breakdown of Operation and Maintenance Costs:

	Rotary Kiln	Fluidized-Bed	Multiple-Hearth
Maintenance	24%	17%	26%
Labor	49%	27%	44%
Light and Power	8%	11%	5%
Fuel	5%	37%	12%
Ash Disposal	2%	1%	2%
Supplies & Misc.	12%	7%	11%

(Refs. 131,135)

f. Pyrolysis

Pyrolysis, basically a coking process, involves heating under pressure in the absence of oxygen. The basic purposes are to decompose complex organics to simpler materials and to drive off the volatiles in gaseous form.

The by-products of pyrolysis are gases and molten fluid. The gases can be collected and utilized as fuel and the molten fluid cools to a solid of varying densities, depending upon cooling times. The literature is lacking with respect to practical applications of pyrolysis to sewage sludge. However, a brief description of the application of the pyrolysate from sewage sludge pyrolysis as a filter material is offered (Ref. 111).

The pyrolysate was tested for its adsorption capabilities and the results compared to the adsorption tests results for activated carbon and fly ash. The adsorptive tests included tests on crystal violet dye and COD. Table III-D-15 summarizes the results of the COD adsorptive test.

Table III-D-15
COD ADSORPTIVE TEST OF PYROLYSATE

Adsorbent	Initial COD	Final COD	Removal %
Carbon	53.5 mg/l	10.2	81.0
Pyrolysate 14% C	53.5 mg/l	32.6	39.1
Fly Ash	53.5 mg/l	49.8	6.8

(Ref. 111)

The study concluded that the adsorptive capability of pyrolyzed sewage sludge is somewhere between that of activated carbon and fly ash (Ref. 111).

5 - Combined Sewage Sludge - Refuse Incineration

Incineration of sewage sludge and refuse in separate units is the norm in the U.S. today. It would seem, on the surface, that the combination of the two processes might prove economical. However, two factors must be contended with in any combined burning process: (1) hauling costs and (2) sewage sludge moisture (Ref. 154).

Collection and hauling costs generally account for greater than 50 percent of total refuse disposal costs. For this reason municipalities usually install incinerators in central locations. This practice could make the combined hauling costs of sludge and refuse prohibitive. The savings that could probably be effected by combined incineration of refuse and sludge may very well be offset by increased transportation costs for collected refuse taken to uncentralized incineration sites and/or from sludge hauling costs when more centralized refuse collection sites are involved. However, this implies that it may be more advantageous for smaller communities to utilize combined incineration, since their hauling costs are likely to be far more modest.

It is of utmost importance to maintain a low uniform moisture in the feed to a combined incinerator (Ref. 154). This necessitates dewatering of sludge to 75 percent moisture content. This dewatering and mixing of sludge with refuse has been accomplished successfully for many years in Frederick, Maryland (Ref. 97). Flash drying and rotary kiln processes described earlier in the text can accommodate combined refuse-sludge incineration. In both processes, the dried sludge can be mixed with refuse prior to its entry into the incinerator

combustion chambers. The requirement for auxiliary fuel is not completely met with the combustion of refuse. It is, however, significantly reduced since refuse does have some auxiliary fuel value.

6 - Engineering Survey for Incinerator Sites (based on USPHS-85)

Introduction. The checklist following this section is designed to aid the engineer in obtaining the information required to perform a valid evaluation of a potential incinerator site.

1. Site Location. The location of the site is important for future field investigations and in order to incorporate the incinerator facility into the existing transportation and sewerage network.

2. Geometry of Site. This information will be required during feasibility studies, since during this type of study placement of facilities and movement of equipment will be important considerations.

3. Present Owner. It is necessary to establish the ownership of the site since this may influence the land acquisition costs and problems if the site is considered favorable.

4. Land Characteristics. The topography of the site and surrounding areas are critical factors with respect to the intended usage. The topographic features should be described and this information incorporated into site planning work efforts.

Since the site will be developed as an incineration facility, a degree of site preparation will be required. An inventory of the existing drainage facilities may result in a savings in site development costs, if these existing facilities can be utilized.

5. Available Soil and Geological Information. Any construction project in which the supporting strength of the soil is a factor should include a boring contract. This information is crucial to the proper design of foundation structures. Soil data and estimates of seismic activity would be required. Historical records and field tests should be utilized to generate this information.

6. Meteorology. Wind conditions are extremely important with respect to dispersion of air contaminants. This is particularly significant in San Francisco where the predominant on-shore wind concentrates pollutants in valleys and in some cases renders air quality unacceptable.

The amount of rainfall anticipated is important for two reasons. First, this data will determine the on-site drainage facilities required. Secondly, periods of excessive rainfall can hamper operations by making access roads difficult to use.

7. Operational Support. The responsibilities for providing adequate fire fighting facilities should be determined. The fire demand for the site should be determined and existing water networks evaluated for their adequacy.

All utility needs for the incineration facility must be determined. The location and adequacy of existing utilities must be determined to aid in developing cost estimates for utility support.

8. Physical and Governmental Constraints. The governmental regulatory agencies having jurisdiction over the proposed operation should be identified and contacted. Their requirements should be obtained and reviewed, including zoning restrictions.

9. Existing Operations. A listing of other sludge disposal facilities serving the area should be prepared. This will allow an accurate assessment of the additional sludge disposal needs and will avoid duplication of services offered.

10. Site Access. The responsibility for maintaining access roads should be determined. In addition, loading restrictions of road surfaces and bridges which may be utilized for site access should be determined.

Hauling regulations should also be investigated to determine whether or not it is permissible to haul waste materials along the available routes.

The availability of waterway access should be considered as a method of sludge transportation.

The compatibility of the site with a potential sludge pumping operation should be determined. Important factors include distance from origins of sludge and terrain restrictions.

11. Residue Disposal. The methods of residue disposal allowed by local regulations should be determined. The locations of suitable disposal sites should be catalogued for cost estimating purposes.

Preliminary Engineering Survey for Incineration Sites (based on USPHS)

I. Site Location

____

II. Site Geometry

Length__________ Width__________ Acreage__________

III. Present Owner

____

IV. Land Characteristics

(a) Topographical Description

____

____

(b) Drainage Facilities

(1) Natural __________ __________ acres

(2) Sewers __________ __________ acres

(3) Open Ditch __________ __________ acres

V. Available Soil, Geologic and Seismic Information

Soil Information ______________

____

____

Geologic Information ______________

____

____

Seismic Information ____________________

____

____

VI. Meteorology

(a) Annual Rainfall

____

(b) Prevailing Wind Direction

____

(c) Frequency and Duration of Temperature Inversions

____

VII. Operational Support

(a) Fire Protection Responsibilities

(1) Owner ________

(2) Public System ________

(3) Costs ________

____

____

(b) Location of Nearest Water Supply Suitable for:

(1) Potable Water Use ________

(2) Process Use ________

(3) Fire Fighting ________

(c) Location of Utilities

(1) Water

(2) Gas

(3) Electric

(4) Telephone

(5) Sewer: Storm and Sanitary

VIII. Physical and Governmental Constraints

(a) Governmental agencies having authority over proposed operation

____

____

____

(b) Zoning

(1) Zoning classification__________________________

____

(2) Enforcement agency___________________________

____

(3) Land use restrictions__________________________

____

(4) Procedures required to initiate proposed land use

____

IX. Existing Operations

(a) Listing of other disposal techniques serving the same area

(1) Public____________________

(2) Private____________________

X. Site Access

(a) Water Access

(1) Navigational restrictions____________________

(2) Cargo regulations____________________

(b) Land Access

(1) Access road owner____________________

(2) Maintenance responsibilities____________________

(3) Traffic load restrictions on roadways and bridges

____

(c) Rail Access____________________

(d) Distances from points of sludge____________________

____

XI. Residue Disposal

(a) Local Regulations Concerning

(b) Landfill operations____________________

____

(c) Disposal Site Location____________________

____

Summary

Report Submitted by________________

Date____________________

7 - Environmental Evaluations

Introduction. The treatment of a waste material often results in an end product which, by itself, may have substantial impact on environmental quality. The anticipated stack emissions resulting from the high temperature volume reduction of sludge is an example.

The stack emissions, however, are not the only process end products that warrant consideration. A residue ranging from a nearly stabilized liquid from wet oxidation to inert ash from incineration results when high temperature volume reduction processes are applied to sewage sludge.

For the purpose of the environmental evaluations, the following aspects of high temperature volume reduction processes are discussed:

1. Anticipated Stack Emissions. Anticipated stack emissions are those values reported by the literature and based on operating tests for existing installations.

2. Residue Composition. Residue composition is extracted from the literature and is based on chemical analysis of actual process residue.

3. Odor Production. The temperature requirements for odor destruction are those reported in the literature, based on tests and combustion theory.

4. Steam Plume. The exit temperature necessary to minimize the production of steam plumes, as reported by the literature, are presented.

Stack Emissions. The gaseous products contain certain contaminants. The particular contaminants regulated by the Bay Area Air Pollution Control District (BAAPCD) standards are particulate matter, sulfur dioxide, hydrocarbons, carbonyls and visible emissions. The allowable emission rates are related to the ambient air quality levels that are considered by the BAAPCD to be unharmful to animal and vegetable life. Usually some consideration is also included in an air quality code for the effects of contaminants on various materials. An example of contaminant effect on a material would be the undesirable reaction resulting from the exposure of protective paint coatings and other finishes to high sulfur dioxide concentration (Ref. 93).

Residue. The ash from an incinerator process such as fluidized bed, multiple-hearth, flash drying or atomized spray units is inert. It has value as a fertilizer due to the phosphate content which can be as high as 10 percent (Ref. 132). This solid residue is a suitable landfill material and can be disposed of on land without burial. A tabular presentation of incinerator ash composition is presented in subsequent sections.

On the other hand, the residue from wet oxidation units, which is liquid upon leaving the reactor, cannot be considered inert. The solids or ash which are commonly separated from the liquid by vacuum filtration or centrifugation retain a significant percentage of the influent sludge Chemical Oxygen Demand (COD). The literature reports that, even when the highest oxidation temperatures are applied, the settled ash may have a COD as high as 2.0 g/l (Refs. 39, 106).

The filtrate or centrate resulting from liquid-solids separation can be expected to contain a high COD concentration near 8.0 g/l (Ref. 106). This concentration requires that the liquid portion undergo additional treatment prior to final disposal.

Odor Production. Whenever temperatures in drying or combustion chambers fall below 1100°F, difficulties with objectionable odors will most likely occur. Since many of the high temperature volume reduction processes contain areas where temperatures are frequently below 1100°F, the odor production problem must be considered.

Steam Plume. The stack gases from all high temperature volume reduction processes contain a certain percentage of water vapor. The presence of this water can result in the formation of a steam plume as the gases leave the stack. This plume, although not posing a threat to health, is often misinterpreted as a dangerous pollutant, thereby stimulating objections from concerned individuals. It is therefore desirable to minimize the extent of this problem by immediate dissipation of the water vapor into the surrounding atmosphere.

Bay Area Air Pollution Control District Regulations. The BAAPCD regulations are discussed in detail in Section III-D-2. Tables III-D-16 and III-D-17 summarize the data presented in that section.

Table III-D-16
SUMMARY OF BAAPCD AIR QUALITY CONTROL REGULATIONS

Contaminant	Allowable Emission	Test Period
Particulate	0.15 gr/SCDF*	15 consecutive minutes
Sulfur dioxide	300 ppm	50 min. in 60 consecutive min.
Hydrocarbons	25 ppm	15 consecutive minutes
Carbonyls	25 ppm	15 consecutive minutes
Ringlemann	1	Not more than 3 minutes in any one hour

*SCDF = Standard Cubic Foot

(From Appendix Section III-D-2)

Table III-D-17
SUMMARY OF BAAPCD SULFUR DIOXIDE CONTROL REGULATIONS
DESIRABLE AIR QUALITY LEVELS

Sulfur Dioxide (ppm)	Total Cumulative Exposure from Midnight to Midnight (hrs)
1.5	0.05
0.5	1.0
0.3	3.2
0.1	9.6
0.04	24.0

(From Appendix Section III-D-2)

End Product Compositions. The following end product compositions represent that value given in the literature.

Wet Oxidation

1. Wet Oxidation Reactor Effluent.

Table III-D-18
WET OXIDATION
CHEMICAL CHARACTERISTICS OF REACTOR EFFLUENT

Effluent Volatile Solids Range % ($400^{\circ}F$)	Reactor Effluent BOD_5 Mg/l	Reactor Effluent COD Mg/l	Settled Effluent BOD_5 Mg/l	Settled Effluent COD Mg/l	Effluent Ash BOD_5 Mg/l	Effluent Ash COD Mg/l
2-2.9	5,420	10,200	4,890	8,300	530	1,900
3-3.9	7,030	13,200	6,410	9,800	620	3,400
4-4.9	8,460	16,600	7,110	11,660	1,350	5,000

(Ref. 106)

As is demonstrated by Table III-D-18, the reactor effluent, settled effluent and ash all have high concentrations of BOD_5. For this reason additional treatment must be considered prior to final disposal. The reactor effluent is amenable to treatment by activated sludge or trickling filter processes, and will not depreciate the quality of the process effluent (Ref. 106).

2. Wet Oxidation Exhaust Gases. Table III-D-19 summarizes typical wet oxidation exhaust gases composition.

Table III-D-19
TYPICAL WET OXIDATION EXHAUST GAS COMPOSITION

Contaminant	% by Volume*
Hydrocarbons	0.02
Hydrogen	0.4
Nitrogen	82.8
Oxygen	2.0
Argon	0.9
Carbon Dioxide	13.9

*without afterburner
(Ref. 106)

From the above data it is not possible to determine the actual concentration of hydrocarbons in mg/l because the quantitative analysis of the various hydrocarbons (C_2-C_6) is not known. Since the maximum operating temperature is only 600^{o}F, intermediate combustion products such as hydrocarbons are to be anticipated. The wet oxidation system presented in this report includes provisions for an afterburner arrangement. This pollution control device will provide the temperature range required for the oxidation of hydrocarbons.

3. Wet Oxidation Residue. As previously stated, wet oxidation ash has a BOD_5 concentration of approximately 1.0 g/l. It must, therefore, be treated prior to disposal. Adequate treatment includes activated sludge and trickling filter processes or ash lagoons. Table III-D-20 presents an analysis of the metals found in wet oxidation residue.

Table III-D-20
TYPICAL METALS COMPOSITION OF WET OXIDATION RESIDUES

Metals Present in Settled Residue (Ash)

Metal	%
Iron	4.9
Potassium	0.76
Silicon	3.8
Calcium	0.87
Sodium	0.12
Zinc	.04

(Ref. 106)

4. Conclusions. If provisions for treatment of reactor effluent and secondary combustion of exhaust gases are made, the installation and operation of wet oxidation units should present no significant threat to environmental quality.

Multiple-Hearth

1. Multiple-hearth Stack Emissions. Table III-D-21 summarizes the results of stack tests on incinerator emissions in San Mateo, California. A properly designed and operated multiple-hearth incinerator,

similar to the facility in San Mateo, can be expected to comply with the BAAPCD standards.

Table III-D-21
SUMMARY OF STACK EMISSIONS - SAN MATEO, CALIFORNIA
MULTIPLE-HEARTH INCINERATOR

Contaminant	Measured Test Value	Allowable
Particulate (gr/SDCF)	0.02	0.15
Hydrocarbon (ppm)	2.2	25
Carbonyls (ppm)	7.6	25
Carbon Dioxide (ppm)	25	---
Ringlemann	Steam Plume	1

(Ref. 132)

2. Multiple-hearth Residue Analysis. The multiple-hearth incinerator ash is inert and poses no threat to environmental quality. Table III-D-22 presents a partial chemical analysis.

Table III-D-22
PARTIAL ANALYSIS OF TYPICAL MULTIPLE-HEARTH INCINERATOR ASH

Material	%
SiO_2	24.0
Fe_2O_3	3.0
CaO	27.5
Na_2O	0.4
K_2O	0.10
P_2O_5	11.2

(Ref. 128)

3. Multiple-hearth - Ash Handling. A localized environmental problem can develop due to the mechanical handling of the ash. As the cooled ash drops to the bottom hopper it can be removed mechanically. This dry handling of the ash can result in dust accumulations, which may produce unacceptable conditions within the incinerator building. To minimize this problem it is desirable to utilize hydraulic or pneumatic ash handling systems.

4. Multiple-hearth - Odor Production. The temperature of the exhaust gases leaving the drying hearth is 800°F. It can be expected that this condition will result in odor production. The wet scrubbers that are employed as air pollution devices lend some assistance in reducing odor. However, it may be considered prudent to route these exit gases through the combustion hearths or through an afterburner to eliminate odor. Provisions for re-cooling the gases before entering the scrubber would have to be included.

5. Multiple-hearth Steam Plume. It is generally accepted in the literature that an exhaust gas temperature of 110°F will permit immediate dissipation of water vapor upon entering the atmosphere (Refs. 116, 131). This exit temperature is easily obtainable with the multiple-hearth equipment.

6. Multiple-hearth - Conclusions. The multiple-hearth is a sludge incineration process capable of complying with BAAPCD stack emission standards. Problems with odors have not been reported for California installations (Ref. 132). However, a determination of the need for additional pollution control devices is required.

Fluidized-Bed Incinerator

1. Stack Emissions. Table III-D-23 summarizes the stack emissions from various fluidized-bed installations.

Table III-D-23
SUMMARY OF TYPICAL FLUIDIZED-BED INCINERATOR STACK EMISSIONS

Contaminant	Measured	Allowable
Particulates gr/SDCF*	0.059	0.15
Sulfur Dioxide (ppm)	186	300
Hydrocarbons (ppm)	0	25
CO_2 (%)	15.5	---
H_2O (%)	25.6	---

*Note: SDCF = Standard Cubic Foot
(Ref. 118)

The values in Table III-D-23 are the maximum values reported for various installations throughout the U.S. All reported installations utilize wet scrubbers as air pollution control devices.

2. Fluidized-bed Incinerator - Ash Analysis. Table III-D-24 presents a chemical analysis of a typical fluidized-bed ash. The ash is inert and is completely unhazardous with respect to disposal by landfill.

Table III-D-24
PARTIAL ANALYSIS OF A TYPICAL FLUIDIZED-BED INCINERATOR ASH

SiO_2	20%
Fe_2O_3	2.7
CaO	15.0
Na_2O	1.4
K_2O	1.4
P_2O_5	5.0

(Ref. 117)

3. Fluidized-bed Incinerator Odor Production. Operating temperatures for all portions of the fluidized-bed reactor are approximately 1500°F. Therefore, no problems with respect to odor production are anticipated.

4. Fluidized-bed Incinerator Steam Plume. The requirement for exit gases to be at a temperature of 110°F can be met by fluidized-bed equipment. Therefore, steam plume formation should be minimal.

5. Fluidized-bed Incinerator Conclusions. The fluidized-bed can comply with all of the environmental quality restrictions in the Bay Area. However, it should be noted that scrubber performance should be monitored closely. The high operating temperatures resulting in high exhaust gas velocities increase scrubber particulate loadings. These loadings can be as high as 1.2-3.4 gr per standard dry cubic foot of stack gas (Ref. 118). Loadings such as this increase erosive

action and decrease scrubber and heat exchanger operation lifetimes (Ref. 131).

Other Processes. The other processes under consideration in the high temperature volume reduction portion of this report are:

1) Flash drying
2) Atomized spray technique
3) Rotary kiln

Insufficient material has been published to permit an environmental assessment of the above processes. However, with the following two exceptions, there appear to be no serious hazards presented by any of the above techniques.

1. Rotary Kiln. The exit temperature of exhaust gases from the drying kiln is only 250°F. This temperature is well below the level required for odor destruction. This is a problem similar to the potential odor production problem of multiple-hearth units. Therefore, a similar solution will apply, that is the addition of an afterburner or a recycling of drying gases through combustion chambers.

2. Flash Drying. Associated with the flash drying process are large quantities of particulate emission. The emissions can result in a huge dust cloud, which, in the case of the Chicago, Illinois installation, brought about a termination of operation (Ref. 194). This dust cloud can be a pollution problem and therefore does pose a threat to environmental quality.

Conclusion. The processes discussed in the high temperature volume reduction section can be designed and operated in a manner that will minimize adverse air environmental impacts. The following reasons are offered in support of this statement.

1. All of the processes discussed, with the exception of flash drying (with refuse as auxiliary fuel), when equipped with a scrubber, can satisfy BAAPCD stack emission regulations. More complicated air pollution control systems or a scrubber followed by high efficiency cyclones or electrostatic precipitators can be utilized to minimize particulate emissions from mixed refuse furnaces.

2. Potential odor problems can be effectively eliminated by regulation of gas temperatures and use of afterburners.

3. Process residue is either inert or amenable to biological treatment and can be disposed of safely.

8 - Sub-Appendix: Excerpts from the San Francisco Bay Area Pollution Control Standards

a. Definitions

§ 2033 **Standard cubic foot** of a gas means that amount of the gas which would occupy a cube having dimensions of one foot on each side, if the gas were at **standard conditions**; calculations to determine the number of **standard cubic feet** corresponding to actual measured conditions shall follow accepted engineering practice.

§ 2034 **Standard dry cubic foot** of a gas means that amount of the gas which would occupy a cube having dimensions of one foot on each side, if the gas were free of water vapor and at **standard conditions**; calculations to determine the number of **standard dry cubic feet** corresponding to actual measured conditions shall follow accepted engineering practice.

§ 2035 **Sunset** and **sunrise** mean the times of civil sunset and civil sunrise in San Francisco.

§ 2036 **Type "A" emission point** means an opening of reasonably regular geometry, preceded by a **containing device** which has a minimum length six times the **significant dimension** of the **emission point** and within such minimum length: has a reasonably straight gas flow channel: has smooth interior surfaces; has **area** and geometry essentially constant and equal to the **emission point**; and does not cause a significant change in the gross direction of gas flow.

§ 2037 **Type "B" emission point** means any **emission point** not qualifying under § 2036 as a **Type "A" emission point**.

§ 2038 Quantity of **emission** from a **Type "B" emission point** shall be the quantity of **emission** computed by multiplying the quantity of **emission** from a test **area** by the proportion which the whole **area** bears to such test **area**. Such test **area** may be taken as the cross sectional **area** of the inlet to a sample probe. The **emission** from any test **area** of a **Type "B" emission point** shall be deemed to be representative in every respect of the **emissions** from the whole **area** of such **Type "B" emission point**. **Emissions** from the test **area** may be measured at the place and by the procedure which result in the highest measurement of air contaminants. This section shall not apply if other sampling and testing facilities which will disclose the nature, extent, quantity, and degree of air contaminants are provided by the **person** responsible for the **emission**.

b. DIVISION 3 – GENERAL LIMITATIONS AND REQUIREMENTS

§3000 This division applies to all **source operations**; namely, **incineration, salvage, heat transfer, general combustion**, and **general operations** as defined in §§1110.1 through 1110.5 of Chapter 1, Division 1, unless such **source operation** is excluded under Chapter 2, Division 1.

CHAPTER 1 – GENERAL LIMITATIONS

§3110 VISIBLE EMISSIONS. Except as provided in §§3111 through 3114, no **person** shall cause, let, permit, suffer, or allow the **emission** for more than three minutes in any one hour of a gas stream containing air contaminants which, at the **emission point** or within a reasonable distance of the **emission point**, is *(Amended by Resolution No. 398, dated March 3, 1965)*

§3110.1 As dark or darker in shade as that designated as No. 1 on the Ringelmann Chart as published in the United States Bureau of Mines Information Circular 7718, or *(Amended by Resolution 635, Dated Nov. 5, 1970)*.

§3110.2 Of such opacity as to obscure an observer's view to a degree equal to or greater than does smoke described in §3110.1; and the determination of such opacity shall be according to procedures in Chapter 6, Division 8.

§3111 Where the presence of uncombined water is the only reason for the failure of an **emission** to meet the limitations of §3110, that section shall not apply. The burden of proof which establishes the application of this §3111 shall be upon the **person** seeking to come within its provisions. *(Amended by Resolution No. 398, dated March 3, 1965)*

§3112 §3110 shall not apply to any **emission** on the basis of any observation of an air contaminant observed while such contaminant is inside a bona fide building.

NOTES TO §3111

Note 1. The Control Officer from time to time prepares and distributes a statement of practice in administering §3111. These statements are not adopted by the Board of Directors as a part of this regulation. They are guides to staff activity and are intended to be helpful guides to the public.

Note 2. Water mist alone is not a "noxious mist" and therefore not an "air contaminant" as defined in Health and Safety Code §24348.3.

c. Gaseous Emissions

§ 3120 SULFUR DIOXIDE

§ 3121 No person shall cause, let, permit, suffer, or allow any emission of sulfur dioxide which results in ground level concentrations of sulfur dioxide at any given point in excess of 0.5 ppm (vol) for 3 consecutive minutes or 0.5 ppm (vol) averaged over 60 consecutive minutes, or 0.04 ppm (vol) averaged over 24 hours, or any of the limits specified in Table 1. § 3121 shall not apply to the ground level concentrations occurring on the property from which such emission occurs, provided such property, from the emission point to the point of any such concentration, is controlled by the person responsible for such emission. *(Amended by Resolution 635, dated November 5, 1970 and by Resolution 674, dated July 22, 1971.)*

§ 3122 Except as provided in § 3123, no person shall cause, let, permit, suffer, or allow the emission of gas containing sulfur dioxide in excess of 300 ppm (vol). All sampling of exhaust gases shall follow the techniques prescribed in Chapter 2, Division 8. For purposes of this section 3122, all sulfur present in gaseous compounds containing oxygen shall be deemed to be present as sulfur dioxide, and analyses of samples taken to determine the amount of sulfur dioxide in exhaust gases shall be made as specified in Chapter 1, Division 9. Tests for determining compliance with this section 3122 shall be for not less than 15 consecutive minutes or 90% of the time of actual source operation, whichever is less. *(Amended by Resolution 635, dated November 5, 1970.)*

TABLE I

3121

MAXIMUM ALLOWABLE SULFUR DIOXIDE GROUND LEVEL LIMITS

SO_2 Concentration ppm (vol)	Total Cumulative Exposure Between Midnight and the Next Succeeding Midnight in Hours
Column 1	Column 2
1.5	0.05
0.5	1.0
0.3	3.2
0.1	9.6
0.04	24.0

(Amended by Resolution 635, dated November 5, 1970, and by Resolution 674, dated July 22, 1971.)

§ 3123 Emissions exceeding the limits established in § 3122 shall not constitute a violation of that section provided that all requirements of this section 3123, to wit, §§ 3123.1 through 3123.9, inclusive, are satisfied.

§ 3123.1 Such emissions shall not result in ground-level concentrations of sulfur dioxide exceeding the limits established by § 3121.

d. DIVISION 4 — INCINERATION AND SALVAGE OPERATIONS

CHAPTER 1 — LIMITATIONS

§ 4110 SULFUR DIOXIDE. No person shall cause, let, permit, suffer, or allow the emission from any incineration operation or salvage operation of sulfur dioxide in excess of the limits provided in §§ 3121 and 3122, Chapter 1, Division 3.

§ 4110.1 No person shall cause, let, permit, suffer, or allow, the emission from any incineration operation or salvage operation of hydrogen sulfide in excess of the limitations provided in §§ 11100 through 11102.8, Chapter 1, Division 11. *(Added by Resolution 635, effective November 5, 1971.)*

§ 4111 VISIBLE EMISSIONS

§ 4111.1 No person shall cause, let, permit, suffer or allow any emission from any incineration operation or salvage operation which does not comply with the visible emission limitations in § 3110, Chapter 1, Division 3.

§ 4111.2 No person shall cause, let, permit, suffer or allow the emission from any incineration operation or salvage operation of particles in sufficient number to cause annoyance to any other person, which particles are sufficiently large as to be visible as individual particles at the emission point or of such size and nature as to be visible individually as incandescent particles. This section 4111.2 shall only apply if such particles fall on real property other than that of the person responsible for the emission.

§ 4112 PARTICULATE MATTER. *(Amended by Resolution No. 258, dated October 18, 1961)*

§ 4112.1 No person shall cause, let, permit, suffer, or allow, any emission from any incineration operation or salvage operation, capable of burning not more than 100 tons of waste or salvage material per day, of particulate matter in excess of a concentration of 0.15 grain per standard dry cubic foot of exhaust gas. For the purposes of this § 4112.1, the actual measured concentration of particulate matter in the exhaust gas shall be corrected to the concentration which the same quantity of particulate matter would constitute in the exhaust gas, minus water vapor, corrected to standard conditions, containing 6% oxygen by volume, and as if no auxiliary fuel had been used. *(Amended by Resolution 258, dated October 18, 1961 and amended by Resolution 635, dated November 5, 1970.)*

§ 4112.2 No person shall cause, let, permit, suffer, or allow, any emission from any incineration operation or salvage operation, capable of burning more than 100 tons of waste or salvage material per day, of particulate matter in excess of a concentration of 0.05 grain per standard dry cubic foot of exhaust gas. For the purposes of this § 4112.2, the actual measured concentration of particulate matter in the exhaust gas shall be corrected to the concentration which the same quantity of particulate matter would constitute in the exhaust gas, minus water vapor, corrected to standard conditions, containing 6% oxygen by volume, and as if no auxiliary fuel had been used. *(Amended by Resolution 258, dated October 18, 1961 and amended by Resolution 635, dated November 5, 1970.)*

§ 4112.3 Calculation of the corrected concentration from the actual measured concentration shall be as given in Chapter 1, Division 8. Tests for determining compliance with §§ 4112.1 and 4112.2 shall be for not less than 50 minutes in 60 consecutive minutes, or 90% of the time of actual source operation, whichever is less. *(Added by Resolution 635, dated November 5, 1970.)*

§ 4113 HYDROCARBONS AND CARBONYLS. No person shall cause, let, permit, suffer, or allow the emission from any incineration operation or salvage operation of an exhaust gas containing a concentration of more than 25 ppm (vol) of total hydrocarbons, or a concentration of more than 25 ppm (vol) of total carbonyls. For purposes of this § 4113, the actual measured concentrations of hydrocarbons and carbonyls in the exhaust gas shall be corrected to concentrations which the same quantities of hydrocarbons and carbonyls would constitute in the exhaust gas minus water vapor, corrected to standard conditions, containing 6% oxygen by volume, and as if no auxiliary fuel had been used. Calculation of this corrected concentration from the actual measured concentration shall be as given in Chapter 1, Division 8. For the purposes of this § 4113, total hydrocarbons shall be the sum of the concentrations in ppm (vol) of the individual concentrations of C_2 and higher saturated and unsaturated hydrocarbons, as measured by gas chromatography as described in Chapter 4, Division 9. Total carbonyls shall include aldehydes and ketones determined as described in Chapter 5, Division 9, and calculated as formaldehyde, each carbonyl group being deemed equivalent to one molecule of formaldehyde. Tests for determining compliance with this § 4113 shall be for not less than 15 consecutive minutes or 90% of the time of actual source operation, whichever is less. *(Amended by Resolution 635, dated November 5, 1970. Amended by Resolution 674, dated July 22, 1971.)*

any practice or combination of practices intended or designed to evade or circumvent the basic requirements of this regulation.

§7211 Nothing in this regulation is intended to permit any practice which is a violation of any statute, ordinance, rule or regulation.

§7212 This regulation is not intended to apply to the quality requirements for the workroom atmosphere necessary to protect an employee's health from contaminants emitted by his employer; nor is it concerned with the occupational health factors in an employer-employee relationship.

§7213 Wherever in this regulation a section makes a requirement for emissions, and other provisions of this regulation are less restrictive as to emissions under certain conditions or operations, violation of the most restrictive requirement shall be a violation of this regulation unless the person responsible for the emission shall establish that a less restrictive part of this regulation applies in the specific case.

§7214 When the person who is the owner of a source operation is not the same as the person who is the owner of the emission point discharging air contaminants which originate in such source operation, the person who is the owner of the emission point shall be responsible for complying with this regulation. For the purposes of this section 7214, "owner" shall include owner, lessee, tenant, licensee, manager or operator, or any of such.

§7215 SEVERABILITY. If any provision, clause, sentence, paragraph, section or part of this regulation or application thereof to any person or circumstance shall for any reason be adjudged by a court of competent jurisdiction to be unconstitutional or invalid, such judgment shall not affect or invalidate the remainder of this regulation and the application of such provision to other persons or circumstances, but shall be confined in its operation to the provision, clause, sentence, paragraph, section or part thereof directly involved in the controversy in which such judgment shall have been rendered and to the person or circumstance involved, and it is hereby declared to be the intent of the Board of Directors that this regulation would have been adopted in any case had such invalid provision or provisions not been included.

e. DIVISION 8 — CALCULATION METHODS AND GENERAL SAMPLING PROCEDURES

CHAPTER I — CALCULATIONS

§ 8100 Calculation of emissions of air contaminants shall be accomplished by the calculation methods prescribed in this Chapter 1, or by methods which yield equivalent results. All calculation methods not specifically prescribed in this regulation shall conform to accepted engineering practice.

§ 8110 Correction for the use of auxiliary fuel shall be as specified in § 8111, and correction to a basis of 6% oxygen by dry volume shall be as specified in § 8112. For the purposes of §§ 8111 and 8112 the term "measured volume" shall mean the emitted or metered volume to be corrected, expressed in standard cubic feet.

§ 8111 AUXILIARY FUEL CORRECTION. This calculation is intended to correct the measured volume to the volume which would have existed if the auxiliary fuel had not been introduced, and results obtained by this procedure shall be deemed to represent such correction. The method consists of four steps:

(a) Calculate the amount of oxygen required for stoichiometric combustion of the auxiliary fuel, at the rate of combustion occurring during the period of test.

(b) Calculate the composition and quantity of the products of such stoichiometric combustion in oxygen.

(c) Add, to the measured volume, the amount of oxygen calculated in step (a)

(d) Subtract, from the result of step (c), the volume of combustion products calculated in step (b); the result is the measured volume corrected for auxiliary fuel use.

EXAMPLE: Assume that the gases emitted from an operation using auxiliary fuel total 400,000 standard cubic feet during a test period, and have a composition as shown in the "measured" column of the tabulation below. Assume further that auxiliary fuel usage during the test is 6,000 standard cubic feet of methane, CH_4

(a) Stoichiometric Combustion of Auxiliary Fuel

$$\underset{CH_4}{6{,}000} \quad + \quad \underset{2O_2}{12{,}000} \longrightarrow \underset{CO_2}{6{,}000} \quad + \quad \underset{2H_2O}{12{,}000}$$

12,000 standard cubic feet of oxygen required.

(b) 18,000 standard cubic feet of combustion product;
6,000 standard cubic feet CO_2, 12,000 standard cubic feet H_2O

(c) 400,000 + 12,000 = 412,000

(d) 412,000 — 18,000 = 394,000 standard cubic feet

TABULATION OF VOLUME CHANGE (SCF)

Component	Measured	Correction	Final
CO_2	40,000	— 6,000	34,000
CO	8,000		8,000
O_2	21,600	+ 12,000	33,600
N_2	281,200		281,200
H_2O	49,200	— 12,000	37,200
Total	400,000	— 6,000	394,000

§ 8112 OXYGEN CORRECTION This calculation is intended to correct the measured concentration of an air contaminant to that which would exist if the same quantity of air contaminant were contained in a dry volume corrected to an oxygen content of 6%; and results obtained by this procedure shall be deemed to represent such correction. Where correction for the use of auxiliary fuel is applicable, the volume and composition resulting from the correction procedure of § 8111 shall be taken as the measured volume for purposes of this section 8112. The method consists of six steps:

(a) Subtract any water vapor content of the measured volume, to give a dry volume.

(b) Calculate the oxygen content of the measured volume as a decimal fraction of the dry volume obtained in step (a).

(c) From the figure 0.2095 (average atmospheric oxygen content) subtract the decimal fraction of oxygen as obtained in step (b).

(d) Divide the result of step (c) by 0.1495. (This is 0.2095 — 0.06.)

(e) Multiply the dry volume obtained in step (a) by the quotient obtained in step (d) to give the corrected dry volume on a 6% oxygen basis.

(f) Divide the weight of air contaminant, in grains, by the corrected volume obtained in step (e) to give the corrected concentration.

Example:
Assume an emitted gas composition as follows:

Component	% (Vol., wet)	% (Vol., dry)	SCF
CO_2	8.64	9.53	34,000
CO	2.05	2.24	8,000
O_2	8.53	9.42	33,600
N_2	71.36	78.81	281,200
H_2O	9.44	0.00	37,200
Total	100.00	100.00	394,000

Also assume the weight of air contaminant is 7.9 pounds.

(a) 394,000 — 37,200 = 356,800 SCF, dry volume

(b) $\frac{33{,}600}{356{,}800} = 0.0942$, volume fraction of oxygen

(c) 0.2095 — 0.0942 = 0.1153

(d) $\frac{0.1153}{0.1495} = 0.782$

(e) (0.782) (356,000) = 275,800 SDCF, at 6% oxygen, the corrected volume.

(f) $\frac{(7.9 \text{ lb})\ (7000 \text{ gr/lb})}{275{,}800 \text{ SDCF}} = 0.20$ gr/SDCF, the corrected concentration.

atmospheric sampling for sulfur dioxide concentrations in order to fulfill requirements of §§ 3121 and 3123.

§ 8411 OUTLINE OF PROCEDURE. Sulfur dioxide concentrations in the atmosphere at ground-level shall be determined by continuously operated recording instruments so located with respect to each major source that the gas in that locality will be properly measured. In no case shall fewer than three instruments be used.

§ 8412 INSTRUMENT SPECIFICATION. The recording instruments shall be of a type which will continuously detect and record minute-by-minute fluctuations of concentrations of sulfur dioxide in the range from 0.01 ppm (vol) to 1.5 ppm (vol). *(Amended by Resolution 674, dated July 22, 1971.)*

§ 8413 CALIBRATION. All instruments shall be calibrated in their field locations against either standard solutions (or conductivity standards) or separate ambient air samples taken in periods of sufficient duration to give results which the recording apparatus is expected to register during the respective period. These samples are to be analyzed immediately in accordance with the provisions of Chapter 2, Division 9. Alternate methods of at least equal accuracy may be substituted. Calibrations must be at such intervals as to assure valid records.

§ 8414 *(Repealed by Resolution 674, dated July 22, 1971.)*

§ 8415 *(Repealed by Resolution 674, dated July 22, 1971.)*

§ 8416 *(Repealed by Resolution 674, dated July 22, 1971.)*

f. CHAPTER 5 — SPECIFICATIONS FOR TESTING OF INCINERATION OPERATIONS AND SALVAGE OPERATIONS

§ 8510 Any incinerator to be tested shall have been registered.

§ 8511 The incinerator will be tested under a range of operations that includes a detectable degree of smoke-back through the charging doors, except that where either the maximum control and feed settings or the maximum physically possible charging rate of the registered types of materials do not result in such smoke-back, the range of operations shall include a charging rate which is the maximum permitted by such control and physical limitations.

§ 8512 Material charged during the test period will, insofar as reasonably possible, be representative of material normally charged to the incinerator.

§ 8513 Full-time operation is operation using an operator whose sole duty with minor exceptions is the operation of the incinerator for a minimum of 30 hours per week.

§ 8514 Part-time operation is any operation other than full-time operation.

§ 8515 Tests on any incinerator that is operated on a part-time basis shall be accomplished without a preheat period.

§ 8516 Any incinerator to be tested shall be sampled during burn-down as well as during the stabilized and light-up or preheat periods whichever apply.

CHAPTER 6 — PROCEDURE FOR MAKING OBSERVATIONS TO DETERMINE COMPLIANCE WITH § 3110

§ 8600 The provisions of this Chapter shall govern observations of emissions to determine compliance with §3110. These provisions shall be applied to each observation to the extent they are applicable, and to whatever extent time and physical circumstances reasonably permit.

§ 8610 Observations shall be made from any position such that the line of observation is at approximately a right angle to the line of travel of the emitted material.

§ 8611 The plume shall be observed against a suitable background.

§ 8612 Observations during daylight hours should be made with the observer facing generally away from the sun.

§ 8613 Observations during hours of darkness should be made with the aid of a light source.

§ 8614 Readings shall be noted at approximately 15 second intervals during observation, except that intervals up to 1 minute shall be permitted where the appearance of the emission does not vary during such interval.

§ 8615 The general color of the emission during the period of observation shall be noted as a part of the record of observation.

CHAPTER 7 — DETERMINATION OF THE CONCENTRATION OF PARTICULATE MATTER FOR THE PURPOSES OF § 3113

§ 8710 Concentration of particulate matter shall be calculated as the average of at least two tests.

§ 8711 Each such test shall be for a minimum of 30 minutes at a sampling rate of not more than 3.0 standard cubic feet per minute.

§ 8712 Except as limited by minimum time and allowable rate in § 8711 the minimum volume sampled during each test shall be "V_m" standard cubic feet where

$$V_m = 20\,L^{0.8}$$

where "L" is the significant dimension of the emission point in feet.

§ 8713 During the entire period of each test the appearance of the emission shall be observed by the control officer to determine its shade or opacity in the sense of § 3110.

Table III-D-25

SUMMARY OF HIGH TEMPERATURE VOLUME R

Type of HTVR	Characteristics	Performance (% Reductions)	Pretreatment
Atomized Suspension Technique Incineration	Hi-temp, low pressure Op. temp: up to 2000°F Auxiliary fuel required		Thickening, grinding Greater than 8% TS required 14% TS maximum desirable
Wet Air Oxidation Lo Pres. and Temp	Auxiliary fuel required 300-350°F - 300 psig (A heat treatment to aid dewatering)	20-40% raw TVS 10-45% raw COD 13-63% dig. COD	Size reduction thickening to: 3% TS required 6% TS preferred
Hi Pres. & Intermediate Temp	350-500°F - 800 psig	60-80% raw TVS	
Hi Pres. and Temp.	500-550°F - 1200-1800 psig	65-74% raw TS 85-92% raw TVS 80-85% raw COD	
Fluidized Bed Incineration	Op. Temp. 1500°F suited for sludges with high oil and grease content Auxiliary fuel required	85-90% total dewatered wet mass Ash Residue Produced: 1.1 lbs/lb raw TVS, 2% as particulates after scrubbing	Thickening dewatering to: 20-25% TS 30% TS preferred size reduction
Multiple-Hearth Incineration	Op. Temp: 1400-1600°F Auxiliary fuel required for most TS concentrations	90% total cake wet weight Ash residue produced: 1.33 lbs/lb raw TVS, 2% as particulates after scrubbing	Thickening dewatering to: min. 15% TS max. 30% TS
Rotary Kiln Incineration	Op. Temp: 1600-2000°F Op. Temp. for Drying: 250-1100°F Auxiliary fuel required		Thickening dewatering to: 20-25% TS Pug mill size reduc
Pyrolysis	Volume reduction by coking under pressure		

NOTE: CC = Capital Cost TVS = Total Volatile Solids (organics) T/D = t

le III-D-25

PERATURE VOLUME REDUCTION

Pretreatment	Cost	Post-Treatment
Thickening, grinding Greater than 8% TS required 14% TS maximum desirable	6-50 T/D range $73,500-165,000 T/D Capacity CC $41-77/ton Total (i=6%, 25 years) $25-41/ton O&M	Processing of stack gases by cyclone
Size reduction thickening to: 3% TS required 6% TS preferred	$79,300-149,000 T/D capacity $31-120/ton O&M $36-150/ton Total (6%, 25 years) (Table III-D-9)	Treatment of residual organics
Thickening dewatering to: 20-25% TS 30% TS preferred size reduction	(5-500 T/D range) $72,600-138,000 T/D capacity $37.90-72/ton O&M $53.40-102/ton Total (6%, 25 years) (Figure III-D-7)	Wet scrubbing of gases Centrifuging, centrate recycling, ash disposal
Thickening dewatering to: min. 15% TS max. 30% TS	Mixed Organic Sludges: (18-800 T/D range) $52,300-110,000/T/D capacity $18.50-21/ton O&M $29.70-40/ton Total (6%, 25years) Lime Sludges: (20-1300 T/D range) $18,000-31,000 T/D capacity $11.60-19.70/ton O&M $15.60-26.30/ton Total (6%, 25 years) (Figure III-D-11)	Wet scrubbing of gases Ash slurrying, drying and lagooning or hopper
Thickening dewatering to: 20-25% TS Pug mill size reduc.	(10-500 T/D range) (Table III-D-14) $56,800-90,000/T/D capacity $33.50-52.80/ton Total (6%, 25 years) $21.[illegible]-33.50/ton O&M	

nics) T/D = tons per day

d O&M = Operation and Maintenance

2

E. TRANSPORTATION

E. TRANSPORTATION OF WASTEWATER SLUDGES

1 - Transportation Modes and Physical Characteristics

Four basic modes of transport of wastewater sludges are currently being used. 1/ These are:

1) Truck haul overland up to 50 miles in radius, either in dewatered form (50-80% moisture) by ordinary dump truck or in liquid form by tank truck.

2) Rail haul between 50 to 200 miles or more, in liquid form by tank cars or in dewatered form in hoppers.

3) Barge haul between 20 to 150 miles, in dewatered form in open barges or in liquid form in tankers.

4) Pipeline transport, pumped as a slurry through pipelines of lengths from 100 feet up to 200 miles or more.

Sludges are generally handled in three physical conditions: the fluid, the gelatinous and the granular. The basic characteristics of each are:

1) Fluid

Activated sludge	2% solids	98% moisture
Primary sludge	5% solids	95% moisture
Digested sludge	5% solids	95% moisture

2) Gelatinous (Thixotropic)

Centrifuged sludge	20-25% solids	75-80% moisture
Vacuum filtered sludge	25-35% solids	65-75% moisture
Sludge bed dried sludge	40-50% solids	50-60% moisture

3) Granular (solid)

Spray dried sludge	70-80% solids	20-30% moisture
Kiln dried sludge	80-90% solids	10-20% moisture

1/ General references for this Technical Appendix III chapter include: 31,46,119,138-179,194,196.

2 - Pretreatment Required for Transport

Current methods of pretreatment of sludge before transporting to final disposal are outlined in the following paragraphs.

1) Pretreatment required for sludge bed drying and disposal to farm land or landfill:

   a. Anaerobic digestion
   b. Air drying on sand beds

From air drying beds the sludge, at about 50% moisture content, can be handled by pitch forks, loaded on wagons or trucks and hauled to nearby farms to spread on fields as is barn manure. The portion not taken to farms can be used as landfill or burned.

2) Pretreatment required for general disposal to landfill, further drying or incineration:

   a. Anaerobic digestion
   b. Dewatering by vacuum filters or centrifuges

3) Pretreatment required for raw sludge incineration:

   a. Dewatering by vacuum filters or centrifuges

4) Pretreatment required for transport by tank trucks, tank cars, or tanker barges:

   a. Digestion
   b. Concentration to 6 to 10 percent solids

5) Pretreatment required for transport of raw sludge by pipeline:

   a. Screening of large solids and grinding
   b. Maceration or "de-lumping"
   c. Mixing to a homogeneous slurry
   d. Elimination of as much grease as possible
   e. Saponification of the remaining grease by chemicals (caustic)
   f. Addition of chemicals to
      1) Inhibit corrosion
      2) Remove oxygen (by sodium sulfite)
      3) Correct pH to 8±
      4) Reduce friction (lignin compounds or polyphosphates)

5) Coat wall of pipe (by sodium dichromate)

g. Heating if necessary to reduce grease build up

h. Dilution or thickening to desired solids concentrations

6) Optional pretreatment for transport of digested sludge by pipeline only:

a. Screening out large solids or scum

b. Mixing or stirring to a homogeneous slurry

c. Correction of pH to 8 if necessary to avoid corrosion

d. Dilution or thickening to desired solids concentrations

An advantage of sludge digestion is that the sludge is more hygienic after digestion, thus that it can be used for liquid sludge disposal on agricultural land.

Pasteurization is desirable before use on certain crops during the growing season. Two methods are advised:

1) Composting to create the heat.

2) Heating with steam, fueled by digestion gas or fuel oil.

3 - Accessory Facilities Required

The accessory facilities required for the four modes of residual sludges and solids transport consist of the following:

1) For truck haul. For sludge in slurry form, no special facilities are required except truck fill hydrants at digestors. If dry solids are hauled, dewatering equipment, a loading area at the dewatering equipment and gravity or mechanical loading facilities are required.

2) For railroad haul. For wet sludges, pipelines and fill hoses, storage tanks, unloading piping at the receiving point, storage tanks at the receiving end, pumps to move liquid mass to point or points of application are required. For dry sludges, dewatering equipment, truck loading facilities, truck conveyance between the two are required.

3) For barge haul. For dry sludges, the requirements are identical to those for truck haul. For wet sludge, pipelines to the docks, storage tanks at the dock, a return pipeline to the treatment plant, pumps and connecting piping, storage

tanks at the transfer point and transfer pumps and piping connections are required.

4) For pipeline conveyance. Storage tanks at the digestors at the treatment plant, pumping stations for the sludge pipeline, storage tanks at the receiving end and transfer or use facility pumps are required.

4 - Truck, Rail and Barge Transport

For truck rail and barge transport, sewage sludge may be handled in any of the following physical conditions:

1) The semi-solid state as vacuum filter cake or centrifuged solids,
2) The solid state as air-dried cake from open sand beds, compost or lagoon dried material, or heat-dried material,
3) In the fluid state as a liquid slurry, the "wet" sludges.

The moisture content of the sludge, when transported, has the most important effect on the handling methods and the cost of transport by any of these three modes. For comparative purposes, the average moisture content of sludge in the several preparatory conditions in which it may be handled are considered to be as follows:

1) Centrifuged sludge - 75-80% moisture content
2) Lagoon excavation - 60-80% moisture content
3) Vacuum filter cake - 65-75% moisture content
4) Air-dried from sand beds -- 50-60% moisture content
5) Composted sludge - 50-60% moisture content
6) Heat-dried sludge - 10-15% moisture content
7) Gravity thickened sludge - about 90% moisture content
8) Wet digested sludge - 94-97% moisture content

When handled in a solid or semi-solid condition, except in very large plants, the sludge would leave the plant of origin in trucks which would transport it either to the point of ultimate disposal or to a point of transfer to another mode of transport, which may be rail, barges or larger trucks. Storage bins and reloading facilities at the transfer station will effect the transfer in an orderly, clean and efficient manner to the long-haul transport which will usually end at the point of ultimate disposal. Unloading, rehandling and distribution or disposal facilities will be provided at the point of disposal. There might be cases where all modes of transport would be used, but for economy the number of transfers should be kept to a minimum.

Handling facilities at the plant of origin will depend upon the condition in which the sludge is prepared for delivery as follows:

1) For vacuum filter cake or centrifuged solids the filters or centrifuges may be mounted on a floor or platform above the truck loading level and may simply discharge directly into the truck below, or a belt conveyor may be provided to load the trucks from a line of several dewatering units at the same or different levels.

2) Air-dried sludge bed sludge and compost may be loaded by hand with pitch forks or by mechanical loaders, or front-end-loader tractors.

3) Lagoon excavation is usually done by dragline, back-hoe or front-end-loader tractor, depending on the size of the lagoon and moisture content of the sludge in the lagoon. In some large plants lagoons have been flooded and excavated by hydraulic dredge.

4) Heat-dried sludge is customarily bagged at the drier and loaded on the trucks by hand or with a bag loader. Heat-dried sludge is prepared for use as a dry fertilizer. Weather-proof storage is usually provided at the processing plant and at all distributing points.

5) Liquid raw and digested sludge may be drawn, respectively, directly from the settling tanks with no pretreatment, and directly from the digesters, and be pumped to tank trucks via a short discharge pipeline or hose, to railroad tank cars through a pipeline and hose fill connection or to tanker barge through a pipeline and hose fill connection. As drawn, raw sludge will have an average of 3 to 5 % solids, digested sludge an average of 5 percent solids.

Since some difficulties have been experienced with pumping raw sludge with 5% solids, it may be advisable to dilute raw sludge to as low as 1% solids and pump at velocities above 3 ft/sec. to be in the turbulent zone of flow in pipes.

However, for truck rail and barge transport there is a great advantage in reducing the weight and volume to be carried. Therefore, liquid sludge to be transported in tank trucks, rail tank cars or tanker barges is concentrated to from 6 to 10 percent solids, even if the loading pipelines must be cleaned periodically. Experience will dictate the best concentration for a given installation. The concentration should be performed in separate tanks for thickening or dilution, with provision

for continuous mixing for homogeneity. Corrective chemicals may be added if desired.

The liquid sludge may be drawn from digestion tanks, similarly, at approximately 5% solids. It will have less grease and grit which cause most of the trouble in handling raw sludge. It can be drawn by gravity directly to tank trucks or tank cars if a railroad siding is conveniently close or it can be pumped a longer distance through pipeline to rail tank cars or to tanker barges.

Loading equipment for liquid sludge consists of a truck fill stand pipe or hydrant, hose connections or hose fill pipes, and the pumps required to deliver the sludge through pipelines to remote rail tank cars or tanker barger.

The operation of handling semi-solid or solid sludges by truck, rail or barge is much the same as handling earth or other bulk materials, and bagged dried sludge would be similar to handling other bagged dry products. But the transporting of sludge in liquid form has certain unique features. It requires a special tank truck with a fill manhole and vent, a valved outlet spreader pipe on the bottom at the back end of the tank, and a valved blow-off at the center for use in delivering sludge to farm areas where the liquid sludge can be applied directly to the ground. In areas where the truck cannot get into the field, a pump on the truck can deliver the liquid sludge to the field through a hose or portable pipe distributor (Ref. 158). Simple small tank trucks have been used for short hauls, but larger trucks are more economical per ton of sludge delivered. A simple tank truck similar to an oil delivery truck can be used for transfer of liquid sludge to another mode of transport.

Railroad tank car handling of liquid sludge is much the same as any other railroad tank car operation except for delivery at the point of ultimate disposal. At the delivery end the tank cars unload to a sump or ground storage tank from which pumps will deliver the liquid sludge to the points of disposal or to tank trucks for delivery and distribution. Chicago (Ref. 163) has recently begun a 20-tank car train haul of 150 miles from its Southwest plant to a farmland disposal area at Arcola. A run with 3000 tons can be made every 24 hours. Chicago has also recently contracted a barge line and two railroads to transport 7,500 tons of liquid sludge per day from its Southwest plant to a strip mine area southwest of Peoria.

Tanker barge handling of liquid sludge is favorable for very large sludge quantities. For offshore disposal the barges are unloaded by opening valves in the bottom of the barge and allowing the liquid sludge

to discharge into the sea beneath the surface. However, if tanker barges are used for transport across water to another transfer point they have the problem of unloading to the next mode of transport. Pumps and pipelines would be required for unloading and delivering sludge to the next transport facility.

5 - Pipeline Transport of Sewage Sludge

Many long pipelines are in use in the United States for transporting sewage sludge. These pipelines vary in size from 4 to 24 inches in diameter and from 2,000 feet to 20 miles in length. Several are being currently proposed for distances up to 200 miles. The design criteria for these pipelines are much the same as for water lines, but with friction factors and velocity limitation determined by the type and concentration of the material transported.

Early installations of sludge pipelines were designed by empirical rules and proportionate relationships to the friction factors used for water, without sufficient knowledge of the hydraulic characteristics of slurry flow in pipelines. Investigation and experience has progressed so that transport pipelines can now be designed and constructed with assurance of successful operation at reasonable cost. Table III-E-1 lists a number of United States cities currently pumping sludge through long pipelines.

Certain constituents of sewage sludge make it difficult to handle in pumps and pipelines. These are:

1) Grease,
2) Sticks, rags and stringy materials, and
3) Grit.

The solution is to eliminate or neutralize the grease,to screen out the sticks, rags and stringy materials, and to settle out the grit prior to pumping through the pipelines. Since it is not possible to eliminate all of the above nuisance materials, it is desirable to maintain thorough and continuous mixing of the sludge preparatory to pumping, and to construct the pipelines to facilitate cleaning.

Economic design of sludge pipelines requires consideration of controllable factors and due allowance for the uncontrollable variables in sludge flow characteristics. Controllable factors are:

Table III-E-1

U.S. CITIES PUMPING SLUDGE THROUGH LONG PIPELINES (1972)
(References 138,154,156)

City	Length (ft)	Pipe Size (in)	Type of Sludge	Sludge Concentration (%)	Velocity (ft/sec)
Austin, Texas	---	8	Activated	0.8	---
Bay Park, Nassau Co., N. Y.	8,000	10	Digested Primary and Activated	2.8	---
Chicago, Ill.	90,000	14	Raw	1.0-2.0	---
	26,600	12	Raw	2.0-4.0	---
Cleveland, Ohio	71,000	12	Raw	---	---
Elizabeth, N.J. (joint facilities)	4,400	24	Raw Primary	7.5-14.0	---
Houston, Texas	4,300	8	Activated	0.5-1.0	3.0
Houston, Texas	10,000	4	Activated	0.5-1.0	3.0
Houston, Texas	12,000	8	Activated	0.5-1.0	3.0
Houston, Texas	21,000	6	Activated	0.5-1.0	3.0
Houston, Texas	36,000	8	Activated	0.5-1.0	3.0
Jersey City, N.J.	13,150	2-6	Raw Primary	0.85-1.55	---
Kansas City, Mo.	35,000	12	Raw Primary	0.4-1.0	2.83-4.2
Knoxville, Tenn.	16,800	6	Raw Primary and Humus	0.55	---
Los Angeles, Cal.	2,500	12	Raw Primary	5±	---
	40,000	24	Digested	3.73	---
Morgantown, W. Va	---	2	Digested	varies	---
Philadelphia, Pa.	26,400	8	Raw Primary	3.0-4.0	---
	2,000	16	Lagoon Dredged Digested	10	---
Rahway Valley, N.J.	---	8	Raw Primary and Some Digested	2.8-5.0	---
San Diego, Cal.	---	8	Digested Secondary	---	3.2-3.5
Seattle, Wash.	19,000	2-12	---	---	

1) Velocity of flow
2) Temperature of the sludge
3) Solids concentration of the sludge
4) Effective grease and grit removal
5) Changes in pumpability by digestion or pumping aids
6) Type of pipe

Uncontrollable factors are:

1) Residual grease content (not removable)
2) Residual fine grit content (not removable)
3) Type of solids contained in the sludge
4) Viscosity variations and relationships
5) Specific gravity of sludge solids (variable)

Selection of the most economical slurry pipeline system depends on the required pressures and the temperature, corrosiveness and abrasiveness of the slurry.

a. Sludge Types and Special Considerations for Pumping

There are four basic types of sludge pumped through long pipelines:

1) Raw primary settled sludge
2) Digested sludge (primary and secondary)
3) Secondary settled sludge (activated sludge or humus)
4) Dredged sludge from storage lagoons.

These sludge types have different characteristics and must be handled in different manners for pipeline transport. A discussion of each type follows.

1. Raw Primary Settled Sludge (Refs. 138, 142, 152, 153, 154, 174). Raw primary sludge pumping through long pipelines is practiced at Cleveland, Ohio; Philadelphia, Pennsylvania; Boston, Massachusetts; Kansas City, Missouri; Jersey City, New Jersey; Knoxville, Tennessee; Elizabeth-Linden-Roselle, New Jersey; Los Angelels, California; Syracuse, New York; Chicago, Illinois; Columbus, Ohio; and elsewhere.

Experience in the operation of these raw sludge pumps and pipelines over many years has revealed the following practical considerations necessary in successfully handling raw primary sludge in pipelines:

a) Raw sludge slurry should be of low solids concentration.
b) Raw sludge should be kept stirred to a homogeneous mixture prior to pumping.
c) Screenings should be eliminated.
d) Skimmings and as much grease as possible should be eliminated.
e) A constant, relatively high velocity of flow should be maintained in the pipeline.
f) The sludge should be pumped continuously.
g) The pipeline should be flushed out after each use with relatively clear water.
h) The pipeline should be arranged for the easy insertion and removal of a cleaning tool ("pig" or "go-devil") for periodic cleaning.
i) Provisions should be made for the application of steam or hot water or solvents to aid in removal of grease from the pipe.
j) The pipeline should include the following auxiliaries or appurtenances:

    1) Access manholes at frequent intervals
    2) Blow-off drains at all low points
    3) Air reliefs at all high points
    4) Sectionalizing valves in the line
    5) Full area, circular opening valves

k) Bends in pipeline should have long radii.
l) The pumps and pipeline should be designed for a maximum head up to three times the normal working pressure.
m) Pumps designed specially for pumping raw sludge should be used.

The preparation of raw primary sludge for pumping through long pipelines requires the following facilities at the point of origin:

a) A holding storage tank which may be used for mixing and applying chemicals to correct pH, reduce pipe friction, or reduce the collection of grease on the pipe walls. It can be a converted digester or a similarly designed covered tank.
b) A pumping station with positive displacement pumps or centrifugal pumps specially designed for pumping sludge at high heads.

c) Dilution piping connections and controls.

d) A magnetic flow meter to measure the sludge flow.
e) A sludge density meter.
f) Sludge disintegrators to macerate the raw sludge entering the holding tank.
g) Pressure gauges and controls.
h) Optional: a thickening tank to concentrate sludge to higher solids content, depends on disposition of the sludge.

There is much in the literature concerning experience with the accumulation of grease on the walls of raw sludge pipelines and methods of cleaning the lines (Refs. 143, 144, 146, 152, 153). Analysis of the raw sludge at the Deer Island plant in Boston (Ref. 140) revealed the following content:

a) 14 to 20 percent grease
b) Fibrous and stringy material
c) Inorganic fines (fine grit)
d) Miscellaneous material, such as sticks, plastics and soft drink caps and cans

The remedies recommended were:

a) Do not permit grinding and return of screenings to the sewage
b) Operate the screens by head-loss differential
c) Clean grease from pumps and piping by a fuel oil solvent
d) Eliminate skimmings from the raw sludge

At Hartford, Connecticut, Angels (Ref. 143) used "king-size" ice cubes pushed through the line by water pressure weekly to keep the sludge lines clean. About 100 pounds of ice in 4 to 5-inch cubes at 60-80 psi were used. Normal sludge pumping pressure is 35 to 45 psi and may rise to 65 psi before cleaning.

Kling, at Rahway, New Jersey (Ref. 153), used a plastic bag filled with ice cubes as a cleaning tool for long lines and a loaf of pumpernickel bread for short lines ending in the digester. These tools are self-destructive.

At Los Angeles' Hyperion plant (Ref. 144) 12-inch raw sludge lines were cleaned by a special tool ("pig") propelled by hydraulic pressure. Cleaning is required when the Hazen-Williams "C" value drops to 40; or a maximum of 60 days between cleanings is allowed (5 hours with 4 men are required for cleaning one 2,500-foot line). Flushing the lines weekly with secondary effluent under 90 psi extends

the time between cleanings. A radioactive capsule attached to the scraper tool facilitates tracing the tool through the pipeline.

At Alexandria, Virginia (Ref. 146), steam and hot water charged with detergent is injected into the sludge pipeline, at 220°F entrance to 130°F exit temperature, and after 6 hours is flushed out with warm digester supernatant to a sump from which it is pumped to the digester. The pipe is cleaned biweekly and the operation requires 8 hours, 5 pounds of detergent and 15 gallons of kerosene for heating.

2. <u>Digested Sludge</u> (Refs. 144,148,154,156,165). Digested sludge is pumped through long pipelines at Bay Park, Nassau County, New York; Los Angeles, California (Hyperion plant); Morgantown, West Virginia; Philadelphia, Pennsylvania; San Diego, California; Mogden, England; Birmingham, England; The Hague, Netherlands; Chicago, Illinois; and in other locations.

Long digested sludge pipelines are also being considered for use in Cleveland, Ohio, Chicago, Illinois and San Francisco, California (Ref. 148).

Since digested sludge is more hygienic after digestion it can be used for liquid disposal on agricultural land. It thus has a value as a soil conditioner, fertilizer and irrigation supplement. Consequently, the pumping of digested sludge through pipelines to land disposal may become accepted practice in the future.

Digestion removes many of the objectionable characteristics of raw sludge. The grease has been reduced by digestion. The grit has been settled out in the digester. Other objectionable material remains in the digester as scum. Digested sludge is homogeneous as drawn.

Therefore, preparation of digested sludge for pumping through long pipelines will require only the following facilities at the point of origin:

a) A screen to remove large solids or scum.

b) A holding tank for mixing or stirring to keep homogeneous, for correction of pH if necessary to avoid corrosion, and for dilution or thickening to the desired solids concentration.

c) A pumping station with horizontal centrifugal water pumps of proper characteristics.

d) A magnetic flow meter (or meters).

e) A sludge density meter.

f) Pressure gages and controls.

Although the collection of grease on the pipe walls will be slow and may not occur if the pipe velocity is maintained high enough to scour the pipe, it would be advisable to provide for cleaning as recommended for raw sludge pipelines. Similarly, the pipeline should include the following appurtenances:

a) Access manholes at frequent intervals.

b) Blow-off drains at all low points.

c) Air relief at all high points.

d) Sectionalizing valves.

Facilities that may be required at the delivery end of the pipeline are:

a) A thickening tank if greater than pipeline solids concentration is desired.

b) A storage tank (this may be used for thickening by decanting the supernatant).

c) A stirrer in the storage tank if solids concentration is not desired (can be a simple rotating blade hung from a top support bearing with a loose guide at the bottom).

d) Piping connections for inlet and draw-off.

e) Pumps and piping for delivering from storage to points of use.

f) Electric power and lighting.

3. Secondary Settled Sludge (activated sludge or humus). Secondary settled sludge or activated sludge usually will be handled in pipelines within the sewage treatment plant. Excess activated sludge and trickling filter humus is usually returned to the primary tank for sedimentation with the primary sludge. In some cases, however, this

excess secondary settled sludge is thickened in separate tanks and delivered to the digestion tanks or to the sludge transportation facilities for disposal. Since waste activated sludge is difficult to thicken by itself, it may simply be used to dilute other sludges (raw or digested) in preparation for pipeline transportation.

At Houston and Austin, Texas, activated sludge is pumped through pipelines of considerable length at a concentration of from 0.5 to 1.0 percent solids.

Apparently, there would be little difference between pumping waste activated sludge and very dilute digested sludge. Therefore, the criteria for pipeline facilities for waste activated sludge would be the same as for digested sludge with a low solids content.

4. <u>Dredged Sludge from Storage Lagoons</u>. Stored sludge is dredged from lagoons at Philadelphia and this technique is being considered at Chicago (Refs. 159, 165, 178).

This operation is performed by flooding the lagoon and cutting and stirring the consolidated sludge with a floating dredge as a hydraulic dredging operation. In the process there is little control over the size and consistency of the dredged material, which may contain some of the soil or earth from the bottom of the lagoon. Consequently, the pumping of this material resembles the pumping of dredged slurries, and may be operated at solids concentrations of from 8 to 10 percent.

The design criteria for a sludge pipeline should include the following (Ref. 150, 153):

a) The sludge may have a solids concentration of from 3 to 6 percent by weight.

b) The velocity of the liquid in the pipe should be greater than 4 feet per second.

c) The flow in the pipeline should be kept constant and continuous.

d) Bends in pipeline should have long radii.

e) Pumps and piping should be designed for a maximum head of up to twice the working pressure.

f) Any good horizontal centrifugal pump, as used for water, with the proper head/capacity characteristics should be used.

g) Magnetic flow-meter or meters are required.

h) The pipe may be any available pipe material that will stand the probably external loads and the maximum internal pressures and should have tight joints.

i) For corrosion allowance add from 1/8 inch to 1/4 inch thickness to that required for the imposed load for pipe sizes ranging from 8 inch to 24 inch.

j) Protection from damage and from freezing is require -y burying pipes below frost line or by placing a minimum of three feet of cover over the top of the pipe.

b. The Technology of Slurry Pipeline Systems (Refs. 139,150,153,155,170-173)

1. Slurry Types and Flow Characteristics. Two types of fluid flow may be encountered in pipeline slurries: laminar and turbulent flow. Each have different pipe friction-loss factors. Laminar flow occurs at low velocities below a critical point. Turbulent flow occurs at high velocities above a critical point. There is a transition zone between the two flow types in which the viscosity of the slurry affects these critical velocity points, depending on the slurry type. Newtonian slurries (non-plastic) can be treated as true fluids provided the flow velocity is high enough to suspend the solids. The performance of Bingham-plastic slurries is affected by shear stress, rigidity and "yield stress" at any given solids concentration (Ref. 150).

There are two types of slurries, each having different critical velocity and other characteristics. These are:

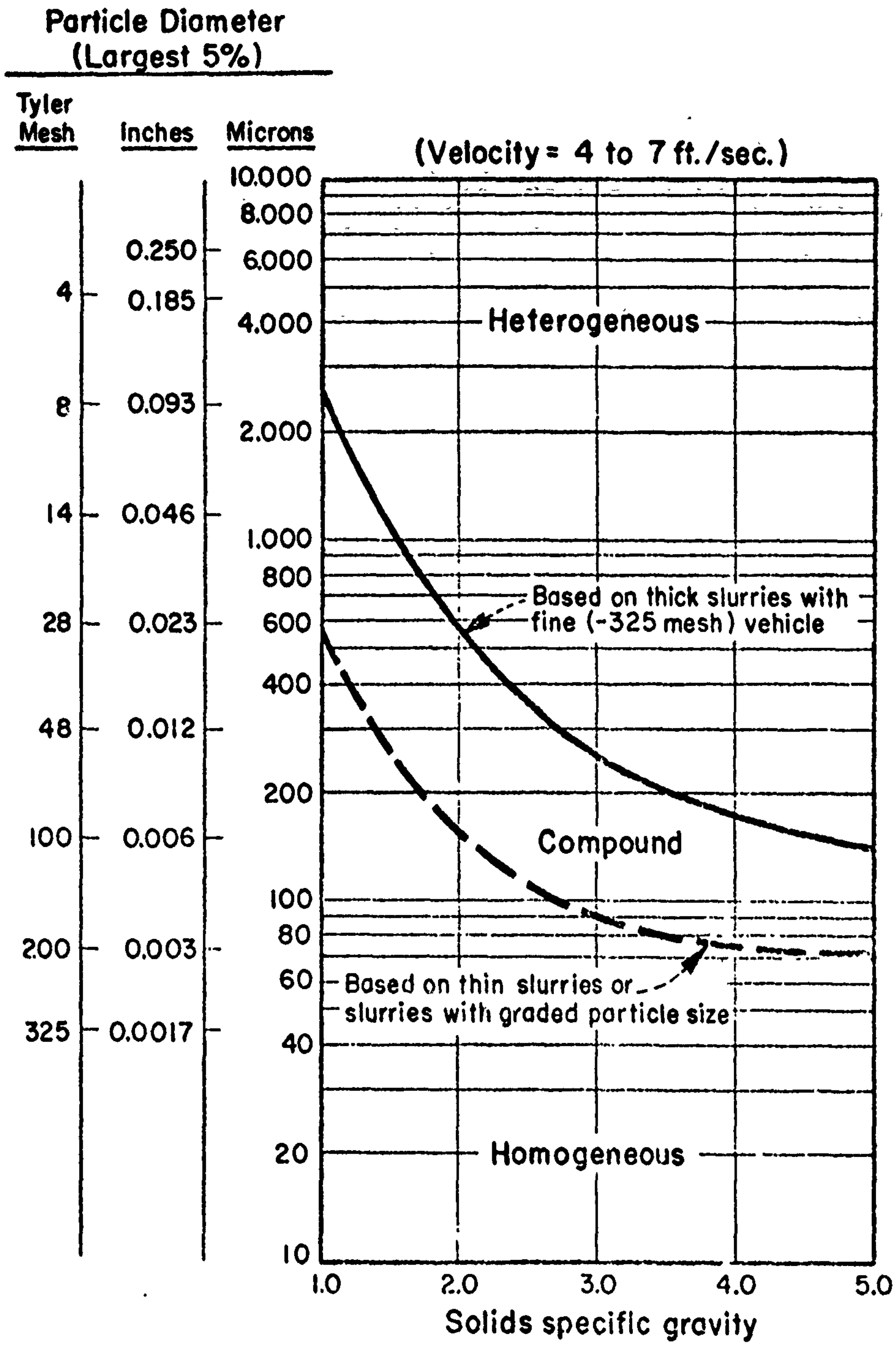
a) Homogeneous slurries exhibit homogeneously distributed solids in a liquid media, fine particle sizes and high solids concentrations, and non-Newtonian-effective viscosity varies with applied shearing strain rate. Examples are sewage sludge, clay slurries and cement-kiln-feed slurries. Homogeneous slurries have a viscous-transition critical velocity, operation below which is acceptable for truly homogeneous slurries. However, no turbulent forces exist to suspend even trace amounts of heterogeneous particles. For homogeneous slurries (i.e. digested sludge) the viscous transition from

turbulent to laminar flow has been defined as the critical velocity. The transition velocity and laminar friction losses are very sensitive to the viscosity, with transition velocity tending to increase with viscosity and therefore with solids concentration, greater quantities or fines and lower solids specific gravity. Transition velocity is directly proportional to diameter for slurries with Newtonian (non-plastic) properties.

b) Heterogeneous slurries tend to have lower solids concentrations and larger particle sizes than homogeneous slurries. There is a vertical concentration gradient present and fluid and solids maintain separate identities. Examples are dredged materials and phosphate rock. The deposition critical velocity is directly related to the settling velocity of the coarser particles and the degree of turbulence. The critical velocity increases with increasing particle size or specific gravity and increasing slurry concentration or viscosity. Deposition velocity also increases in proportion to the square root of the pipe diameter. The velocity of deposition of the coarser particles on the bottom of a horizontal pipe is the critical velocity. For heterogeneous slurries (i.e. raw sludge) the velocity of deposition of the coarser sized particles on the bottom of a horizontal pipe is the critical velocity (See Figure III-E-1). Transition velocity for Bingham-plastic slurries is only slightly affected by pipe diameter.

A mixture of the two slurry types often exists in which the finer particles join with the liquid to form a homogeneous vehicle, while the larger sized particles act heterogeneously. An example of this is a coal slurry. (Raw sewage sludge might come under this classification.) The effect of particle size on deposition velocity is shown in Figure III-E-1.

A velocity range from 4 to 7 feet per second is usually practical and economical. Velocities below 4 fps are seldom desirable. Velocities near 7 fps may be necessary fro some slurries, but abrasion of pipelines can be considerably above 8 fps and can be serious at higher velocities. Within the range of 4 to 7 fps, the pipe friction loss may be computed using a Hazen-Williams "C" factor of 100. "hese velocities can be maintained with periodic cleaning or the use of corrosion inhibiting and flow lubricating chemicals.



(Ref. 150, Fig. 5)

SLURRY FLOW REGIME

Heterogeneous – Homogeneous classification as a function of solids size and specific gravity.

Figure III-E-1

Experiments by W. Rudolphs and L. E. West at the Elizabeth Joint Meeting Plant to determine the effect of solids concentration, viscosity and temperature on the flow of raw sludge through a 24-inch pipeline, 4,400 feet long, at flow rates of 1,000 to 3,500 gpm (sludge loading 2,900 to 3,500 tons per run), gave the results shown graphically in Figures III-E-2, -3 and -4.

The conclusions drawn from these experiments are as follows:

a) There is a material increase in loss-of-head with increased solids concentration, with the rate of flow, and with the increase in viscosity.

b) The temperature of the sludge exerts a greater influence than solids concentration, head loss increasing with decreasing temperatures with greatest effect below 65°F.

c) There appeared to be a lag in temperature effect according to season and subsequent flow velocities, possibly due to bacterial action causing partial liquefaction of the sludge during storage.

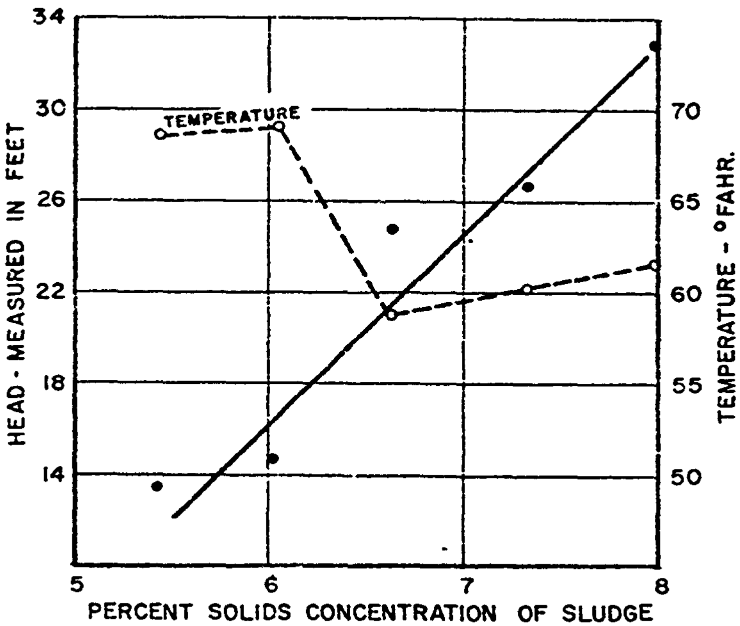
d) The solids content of the sludge appears to effect a gel-like structure of the sludge so that the viscosity and hence the friction losses change.

Experiments were made by J. R. Wolfs at Cleveland, Ohio (Ref. 170) using waste activated and primary sludge, waste activated sludge, digested sludge and chemically conditioned digested sludge flowing through a 2-1/2-inch pipeline to determine:

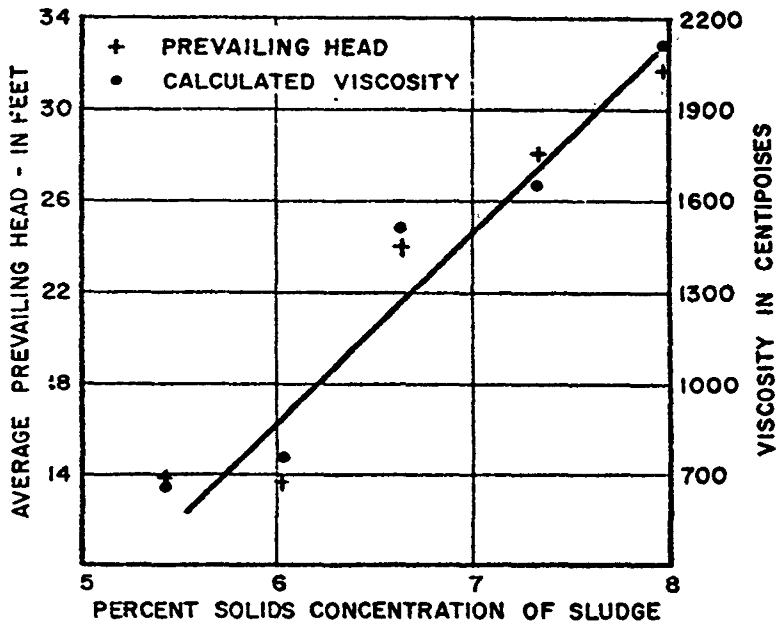
a) The effect of solids content on head loss with the various types of sludge.

b) The maximum possible solids content that could be pumped.

c) The effect on thixotropic properties of sludge of standing for a period of 24 hours.



(A) RELATION BETWEEN PREVAILING HEAD AND CALCULATED VISCOSITIES WITH INCREASING SOLIDS CONCENTRATIONS.

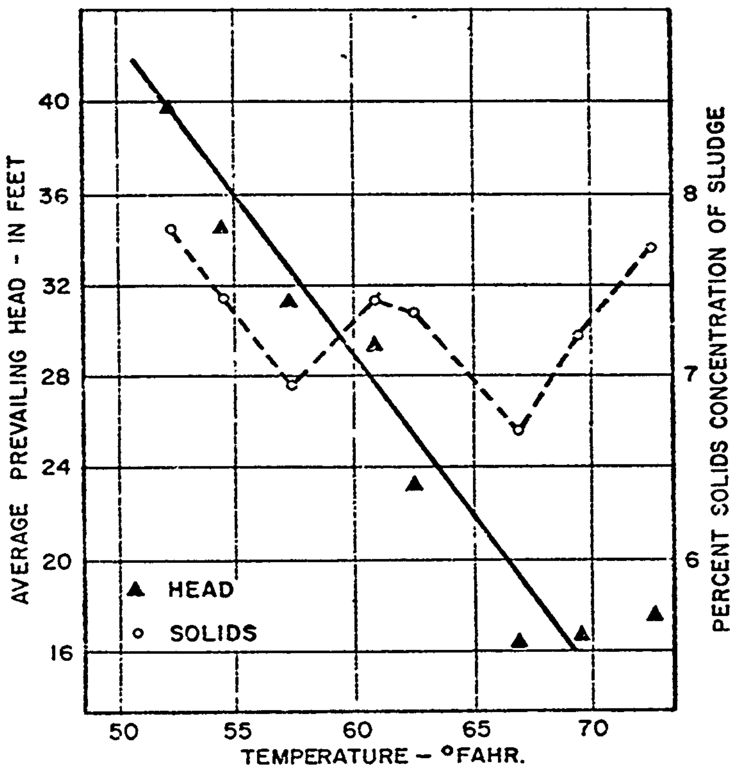


(B) EFFECT OF SLUDGE CONCENTRATION ON PREVAILING HEAD IRRESPECTIVE OF TEMPERATURE OF SLUDGE.

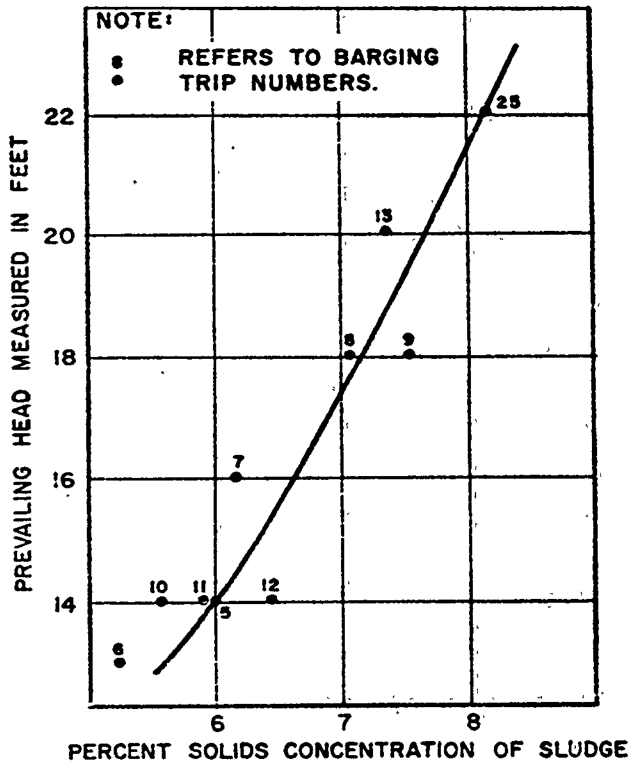
VARIATIONS IN PERCENT SOLIDS CONCENTRATION OF SLUDGE WITH HEAD AND VISCOSITY

Figure III-E-2

(Ref. 173, Fig. 1&2)



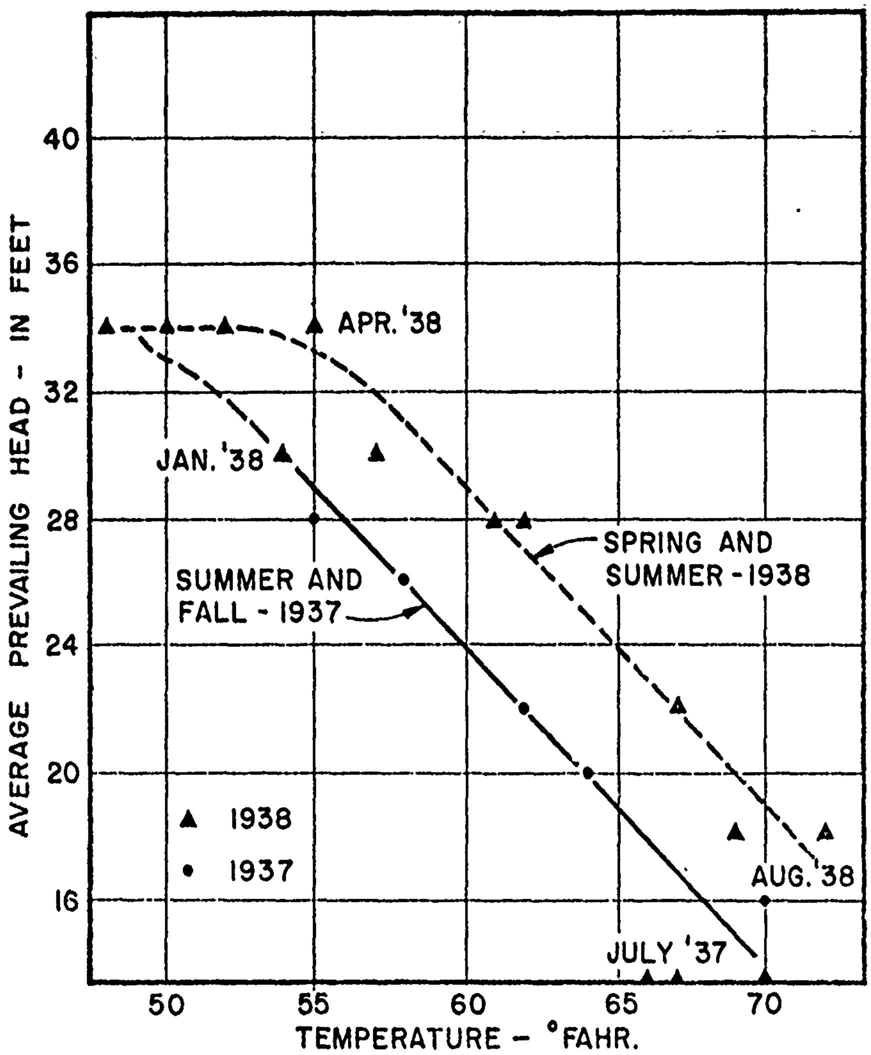
(A) EFFECT OF TEMPERATURE OF SLUDGE ON LOSS OF HEAD



(B) RELATION BETWEEN SOLIDS CONCENTRATION AND LOSS OF HEAD AT ABOUT CONSTANT TEMPERATURE.

VARIATIONS IN PERCENT SOLIDS CONCENTRATION OF SLUDGE WITH HEAD AND TEMPERATURE

Figure III-E-3
(Ref. 173, Fig.3&4)



(Ref. 173, Fig. 5)

SEASONAL EFFECT OF TEMPERATURE ON LOSS OF HEAD

Figure III-E-4

The results indicated that:

a) High head loss occurred at low velocities, with a great range of head loss occurring from a 1-1/2 percent difference in solids content.

b) Thixotropic properties studied by means of a Stormer viscometer showed that thixotropy added to head loss only at lower velocities.

c) At lower velocities the digested and conditioned sludges showed a much lower head loss than the primary sludge, with the solids content being the same.

d) The factors of solids content and the maximum that could be pumped were not determined.

The report of an ASCE Sanitary Division Committee on "Friction of Sewage Sludge in Pipes" published in 1929 (Ref. 175) states the following conclusions:

a) Sludge is neither a viscous nor a homogeneous material but is variable in character.

b) The usual analytical tests do not define its physical qualities, but it seems to behave more like suspended matter.

c) Below the critical velocity sludge has a different friction factor from that above the critical velocity. Below the critical velocity the coefficient of flow cannot be concisely stated and above the critical velocity it can only be expressed in ranges.

d) Sludge friction losses increase with a decrease of moisture content.

e) Sludge friction losses tend to increase with lower temperatures.

f) Sludge friction losses for high velocities (from about 5 to 6 ft/sec. or more) tend to follow more nearly the characteristic law for the flow of water.

g) Friction losses for fresh or undigested sludge and for sludge from combined sewage are more erratic and the determination of a friction factor is correspondingly more difficult.

h) Within the limits investigated no law of sludge flow has been found.

Bertram C. Raynes (Ref. 139) describes the flow characteristics of digested sludge slurries as follows: "Digested sludges exhibit both plastic (Bingham) fluid characteristics as well as non-Bingham, or Newtonian, flow characteristics; below about 5 percent solids the flow is Newtonian. As solids concentration increases about 5 or 6 percent, the plastic nature increases; at 30 percent solids, as in filter cake, sludge can be handled with a common pitchfork. This change in characteristic is of fundamental importance to economic pipeline design. Below 5 percent solids concentration the economics of sludge slurry transport will resemble water transport costs with respect to fluid friction and power requirements."

Turbulent flow occurs at higher velocities for greater sludge concentrations and is abrupt up to 4 percent solids. At 5 percent solids in small pipes (less than 10 inch) turbulence occurs at approximately the same velocities as for water. In larger pipes even plastic sludges will become turbulent in the region of the accepted economic velocities, and head losses will be comparable to those found in pipelining conventional slurries.

Anton E. Sparr (Ref. 153), after a thorough review of the practice of pumping sewage sludge through long pipelines, summarizes the results of his study as follows:

a) Pipe friction head loss varies directly with the viscosity of the sludge flowing within it.

b) Increasing the velocity of flow within the laminar flow zone decreases the apparent viscosity.

c) Increasing the velocity of flow in the turbulent flow zone further decreases the apparent viscosity until the true viscosity of the sludge is reached.

d) Reducing the size of coarse sludge particles reduces the viscosity of the sludge.

e) Effective grit removal is necessary for economical pumping of sludge in a pipeline.

f) Low velocities of raw primary sludge in the laminar flow zone often result in deposits of grease on the wall of the pipe.

g) Digested sludge has lower friction head loss than raw primary sludge of the same solids concentration.

h) Flow velocities in the turbulent flow region tend to prevent deposition of grease within the pipe.

i) Maintaining the operating velocity in the lower portion of the turbulent flow zone results in maximum economy for pumping sludge through a long pipeline.

j) Little or no grease was deposited in a pipeline after many years of pumping low solids activated sludges.

k) Pipeline materials and linings influence pipeline head losses as a result of differing friction factors.

l) Some pipeline materials and linings, such as glass lining, cement lining and fiber-glass-reinforced epoxy pipe resist the adherence of grease more readily than other materials such as cast iron and steel.

2. Pumps and Piping (Refs. 31, 150). Both centrifugal and positive-displacement type pumps are used for slurry pumping, depending on system pressure requirements.

Centrifugal pumps are limited in casing pressure and efficiency. Split-case pumps are used to facilitate replacement of impellers and linings. Impeller tip speed is limited to 440 ft/sec. to reduce wear. Efficiency is low due to the rugged design of the impeller, wide throat impeller clearance and low speed. Fresh water seals are necessary to reduce shaft wear. Rubber linings have been found satisfactory in low pressure pumps. Wear-resistant alloys are used for coarse slurries. By multiple pumps in series final discharge pressures up to 600 psi have been obtained. Booster pumping stations may be used on long lines.

Positive-displacement pumps can be used for high pressures, and for very abrasive slurries, with clear water packing seals. They may be of several types of design: plunger type, piston type, diaphragm and "advancing cavity" type. Pulsation dampeners will be required to reduce hammer and maintain a uniform flow. Replaceable pistons and piston liners may be used in piston type pumps.

The piping system must be designed with provisions for draining, replacement of parts, long radius bends, access for unplugging and

cleaning. Corrosion and erosion must be considered. Rubber lining may be required at wear points in the line. Valves should be full opening and preferably of a type that will not collect material in pockets to restrict operation. Lubricated plug valves or ball valves are commonly used, but are not ideal for slurries, and should have flush and drain connections.

Magnetic flow meters are preferred measuring devices. They are not affected by the solids in the slurry and do not restrict the flow. Positive displacement pumps can be used to measure the flow without meters.

Density meters are available for monitoring the slurry concentration without flow restriction, but require frequent calibration. Diaphragm type pressure gages or hydraulic backflow gauges should be used to measure and record line pressures. Pressure switch shut-offs should be provided at pumps.

6 - Sludge Transportation Costs

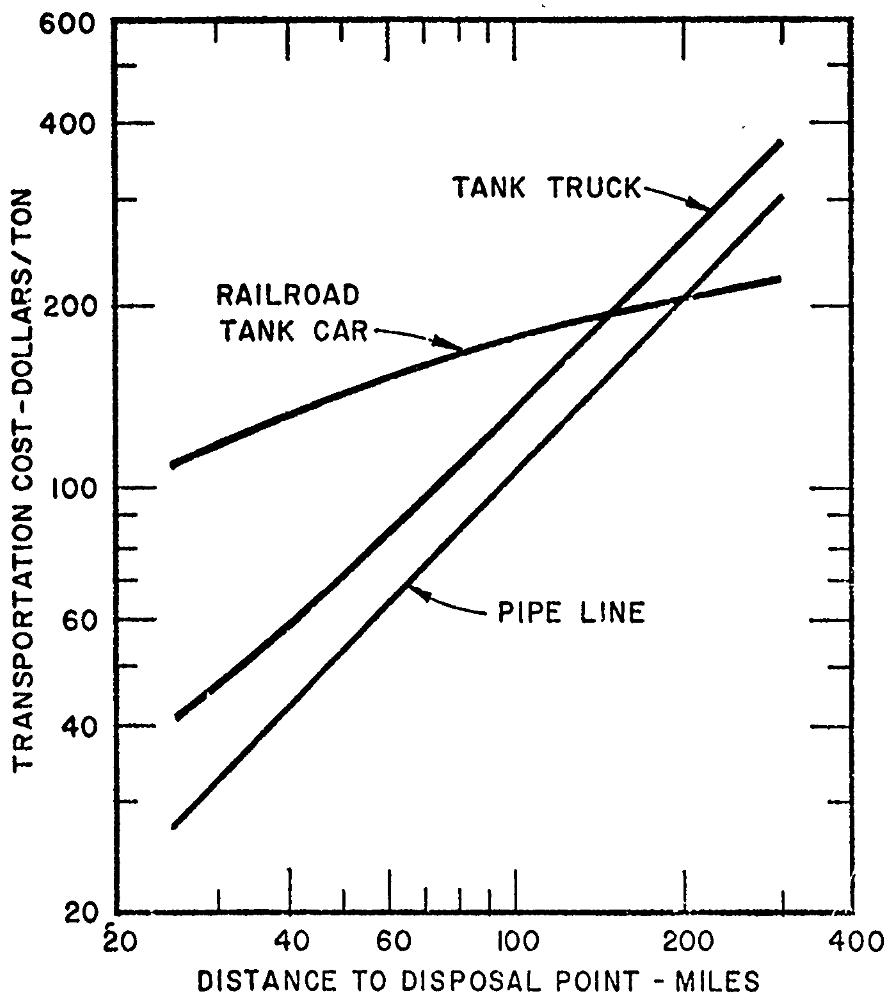
a. Total Cost Estimates

The costs of truck, railroad, barge and pipeline transport modes have been compared and it is found that pipeline transportation is the most economical for large installations. Only for small plants producing less than 5 tons per day of digested sludge solids is trucking more economical than pipeline transportation. Typical costs for the four transport modes are shown graphically in Figures III-E-5 through E-8. Cost bases and interest rates are indicated in the references.

There may be cases where two or more modes are required due to local conditions. In this case the cost of such a combination can be estimated from these curves for decision-making purposes. For project construction, more accurate costs must be obtained from actual field surveys and detailed design.

Table III-E-2 (Ref. 119) compares the cost of filtration and incineration with pipeline transport of liquid sludge to land disposal sites. Costs include facilities at the disposal site, but do not include the cost of digestion.

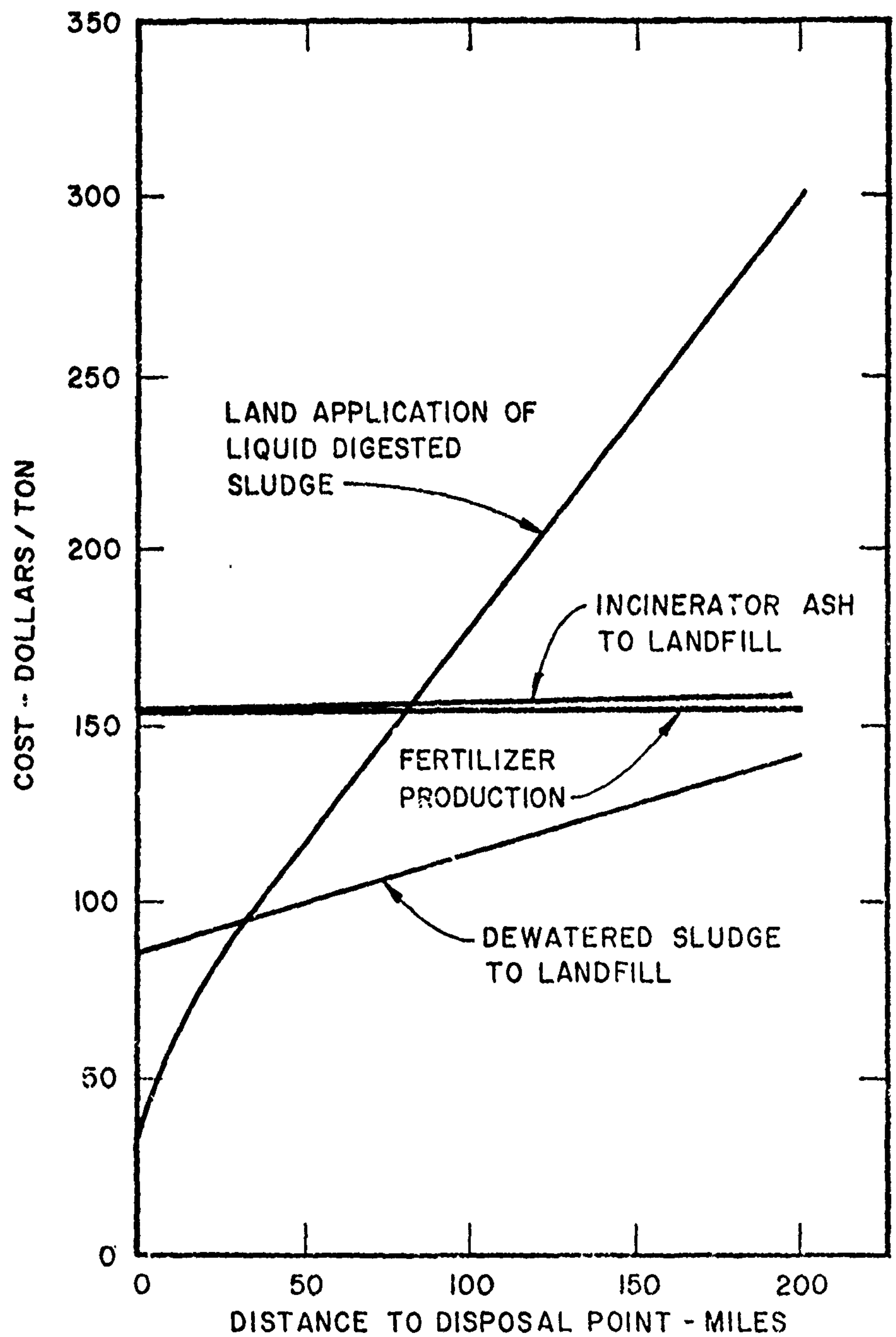
The total cost of any mode of transport consists of loading, transfer and unloading, and hauling costs.



(Ref. 119, Fig. 215)

COST OF TRANSPORTING SLUDGE FROM CITY OF 100,000

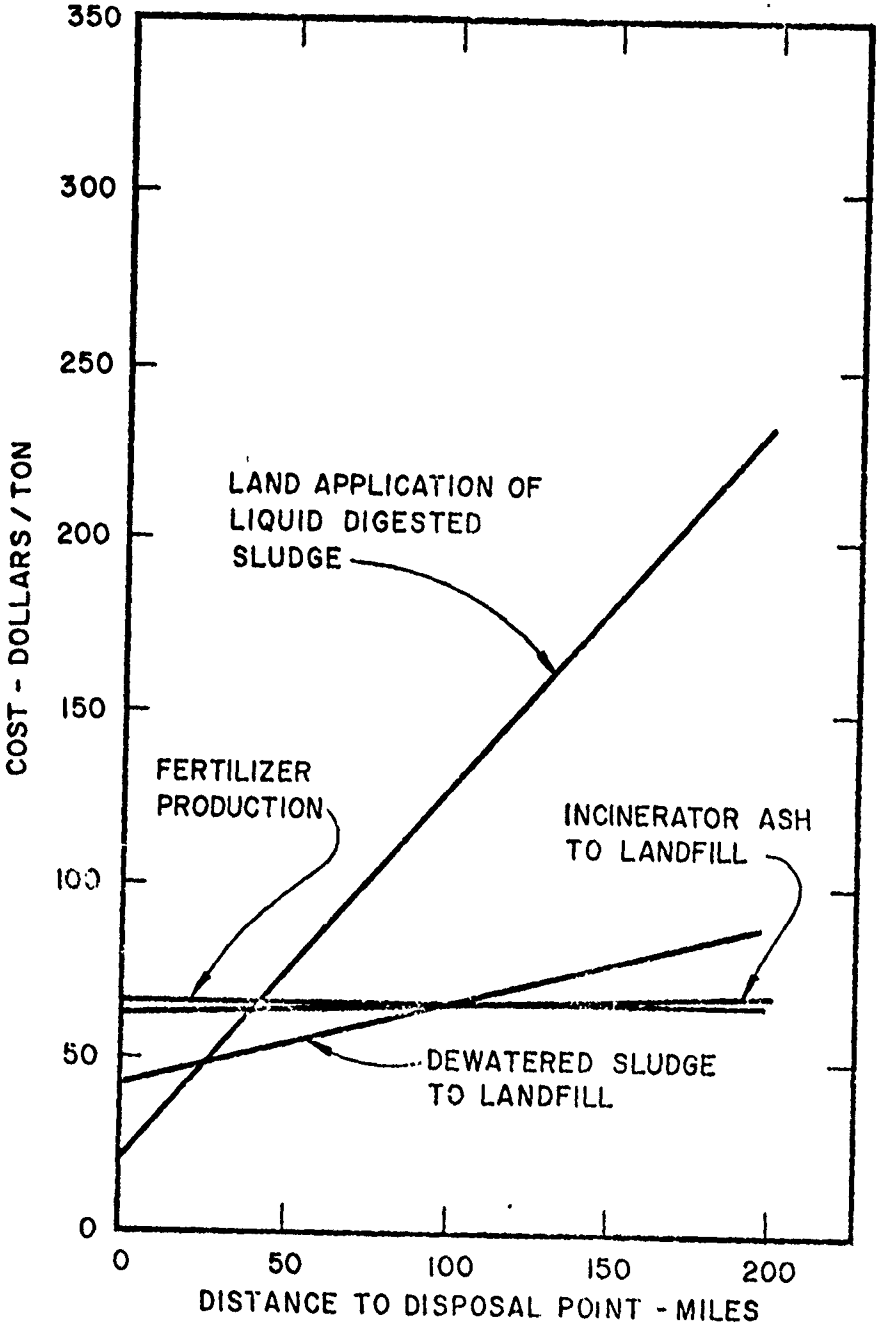
Figure III-E-5



(Ref. 119, Fig. 216)

COST OF SLUDGE DISPOSAL BY VARIOUS METHODS FOR CITY OF 10,000

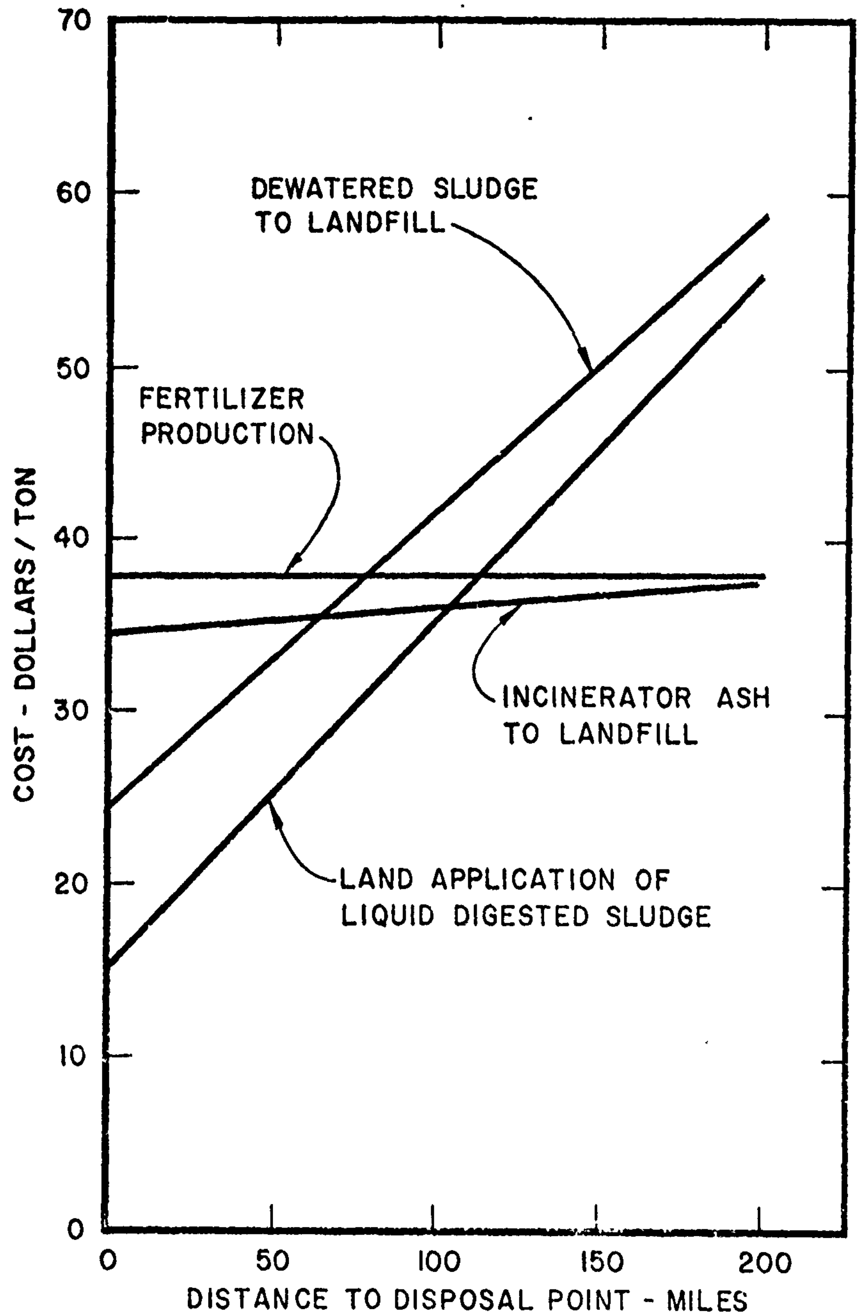
Figure III - E - 6



(Ref. 119, Fig. 217)

COST OF SLUDGE DISPOSAL BY VARIOUS METHODS FOR CITY OF 100,000

Figure III-E-7



(Ref. 119, Fig. 218)

COST OF SLUDGE DISPOSAL BY VARIOUS METHODS FOR CITY OF 1,000,000

Figure III-E-8

Table III-E-2

Effect of Population on Unit Cost of Sludge Disposal: From Raynes (26)

Population: Millions	Cost of Incineration ($/dry ton)	Cost of Land Disposal ($/dry ton)
0.125	67	30
0.25	57	17
0.5	49	11
1	42	8
2	35	5
4	30	4
	(incl. dewatering)	(incl. transportation)

(Ref. 119, Table 60)

Table III-E-3

Comparative Costs of Sludge Disposal

Method	Estimated Cost ($/dry ton)		
	Bacon and Dalton (4)	Baxter (5)	Burd (6)
Incineration	50		
Wet-air oxidation	50	---	42
Multiple-hearth	57	---	30
Fluidized-bed	---	---	30
Drying: fertilizer sale	45	---	---
Lagooning			
Pumping	49	7.23	12
Trucking 5% sludge	---	17.64	---
Trucking 10% sludge	---	12.05	---
Disposal at sea			
Pumping	---	---	11
Barging 5% sludge	---	11.81	12
Barging 10% sludge	---	8.78	---
Land Application			
Landfill	---	---	25
Heat-dried sludge	---	---	50
Dewatered sludge	---	---	25
Liquid sludge	15	---	15
Strip-mine reclamation	16	---	---

(Ref. 119, Table 61)

The cost of loading trucks, railroad cars or barges at the source depends on the loading facilities provided, access to the sludge production point and arrangement of the plant itself. To enable comparisons on an equal basis it will be assumed that the plant of origin will load the trucks, railroad cars or barges within or adjacent to the plant site. Pumping to more remote loading points will have to be charged to that mode of transport. Transfer from one mode of transport to another will be treated as a separate added item of cost. Unloading cost at point of delivery or ultimate disposal will also be treated as a separate added cost, since it will be dependent on the facilities and local conditions at the point of delivery. Cost of distribution or spreading on land will also be considered as a separate cost item. However, in comparing modes of transport, the totals of all costs from the point of origin of the sludge to its ultimate disposal must be compared for any given case.

All costs will be estimated on the basis of dry solids, per ton and per ton-mile, including amortization of the capital cost of the facilities used and replacement of the equipment.

Truck transportation cost will consist of:

a) Loading cost at the plant of origin (will be neglected if loaded on plant site).

b) The cost of haul per ton-mile, reduced to a dry solids basis (based on contractural cost).

c) The cost of unloading to the next mode of transportation or unloading and spreading at the point of ultimate disposal (mostly labor or equipment handling).

Rail transportation cost will consist of:

a) Loading cost at the plant of origin (will be neglected if loaded on plant site).

b) The cost of haul per ton-mile, reduced to a dry solids basis times distance in miles (based on railroad rate schedule or negotiated contractural cost).

c) The cost of unloading to the next mode of transportation or unloading at the point of ultimate disposal.

Barge transportation cost will consist of:

a) Loading cost at plant of origin (will be neglected if loaded adjacent to site).

b) The cost of haul per ton-mile, reduced to dry solids basis (based on contractural cost).

c) The cost of unloading to the next mode of transportation or unloading at the point of ultimate disposal (mostly labor or equipment handling).

Pipeline transportation cost will consist of:

a) Annual cost of capital invested in the installation divided by the total tons of dry solids delivered per year through the pipeline.

b) Annual cost of capital invested in the pumping equipment and piping connections, divided by the total dry tons of solids pumped per year.

c) Maintenance and operator costs per dry ton of solids pumped. Power cost of pumping per dry ton of solids pumped.

d) Distribution costs at point of ultimate disposal, or of transfer to another mode of transport per dry ton of solids transferred.

Table III-E-4 presents cost examples for various truck, rail, barge and pipeline transportation operations.

Figure III-E-9 indicates the effect of sludge volume on transportation costs.

b. Cost Breakdown Examples

Specific cost data are included for selected barge disposal operations to illustrate relative capital and operation and maintenance costs.

1. Westchester County Joint Pollution Control Plant of Yonkers, New York (1960). The plant owns its own barge and all barging facilities, but contracts for operation and maintenance. Sludge handling facilities at the plant consist of:

Table III-E-4

EXAMPLES OF SLUDGE TRANSPORTATION COSTS

Location	Condition of Sludge (% solids)	Cost Base	Total Haul Distance (miles)	Cost Estimate Assumptions	Cost per Ton-Mile Dry ($)
a. Truck Transport					
1) San Francisco	25%	1972	36	Contract Hauling = 3.65/ ton, Dewatering - 15.00/ ton (dry)	0.82
2) San Diego	6%	1972 1/	12	Base Cost = 0.0019/gal Unloading = 2.40/ton (dry)	2.00
	6%	1972 4/	12	Base Cost = 14.00/ton (dry)	1.95
b. Railroad Transport					
1) Standard Uniform Freight Classification	25%	1972	50	2/	1.07
	25%	1972	100	2/	0.62
	10%	1972	50	3/	2.80
	10%	1972	100	3/	1.92
	10%	1972	150	3/	1.51
	10%	1972	200	3/	1.26
2) Chicago (Ref. 31)	5-10%	see Ref.31	150	Contract Hauling = 3.48/ ton, Loading = 0.80/ton	0.36
3) San Diego (Ref. 46)	10%	1972 4/	12	Hauling = 41.00/ton dry Concentration to 10% solids = 2.00/ton dry	6.00
c. Barge Transport					
1) San Francisco	25%	1972	50	Hauling = 7.75/ ton Loading = 1.60/ton Dewatering = 15.00/ton (dry)	1.05
2) San Francisco	10%	1972	50	Hauling = 2.025/ton Concentration = 2.00/ton (dry)	0.45
	8%	1972	50	Hauling = 2.025/ton Concentration = 2.00/ton (dry)	0.55

San Francisco	10%	1972	50	Hauling = 2.025/ton Concentration = 2.00/ton (dry)	0.45
	8%	1972	50	Hauling = 2.025/ton Concentration = 2.00/ton (dry)	0.55
	6%	1972	50	Hauling = 2.025/ton Concentration = 2.00/ton (dry)	0.67
San Diego	10%	1972 4/	12	Hauling = 8.80/ton (dry) Concentration = 2.00/ton (dry)	1.50
New York (Ref. 154)	5-10%	see Ref. 154	12	Hauling = 7 50/ton (dry) Total = 10.00/ton (dry)	0.83
Philadelphia (Refs. 159,165)	10%	1972 4/	120	Total = 5.00/ton	0.70
Baltimore	7.5%	1980	150	Hauling = 22.81/ton (dry) Concentration = 2.19/ton (dry) Loading = 3.20/ton (dry)	0.19
Washington, D. C. (Ref. 154)	4%	1972 5/	200	Total = 20.75/ton	0.15
d. Pipeline Transport (Refs. 148,149,154)					
Chicago	1-7%	1972 4/	75	---	0.11
	1-7%	1972 4/	68	---	0.11
	1-7%	1972 4/	76	---	0.10
	1-7%	1972 4/	45	---	0.13
Cleveland	1-7%	1972 4/	93	---	0.50
Baltimore	1-7%	1972 4/	80	---	0.58
San Diego	1-7%	1972 4/	12	---	1.02

PBQ&D, Inc.

OTES:

1/ Escalated from 1959-60 cost base by a factor of 2.4

2/ For sludge at 25% solids, standard freight classifications are:

Distance (miles)	Rate ($/cwt)	Cost ($/ton)
45-50	0.40	8.00
95-100	0.51	10.20
140-150	0.61	12.20
190-200	0.69	13.80
240-260	0.78	15.60

Also assumes: loading and unloading = 1.60/ton
dewatering = 15.00/ton

... standard freight classifications are:

Baltimore	7.5%	1980	150	Hauling = [illegible]/ton (dry) Concentration = 2.19/ton (dry) Loading = 3.20/ton (dry) Total = 20.75/ton	[illegible]
Washington, D. C. (Ref. 154)	4%	1972 5/	200		0.15

d. Pipeline Transport (Refs. 148,149,154)

Chicago	1-7%	1972 4/	75	---	0.11
	1-7%	1972 4/	68	---	0.11
	1-7%	1972 4/	76	---	0.10
	1-7%	1972 4/	45	---	0.13
Cleveland	1-7%	1972 4/	93	---	0.50
Baltimore	1-7%	1972 4/	80	---	0.58
San Diego	1-7%	1972 4/	12	---	1.02

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NOTES:

1/ Escalated from 1959-60 cost base by a factor of 2.4

2/ For sludge at 25% solids, standard freight classifications are:

Distance (miles)	Rate ($/cwt)	Cost ($/ton)
45-50	0.40	8.00
95-100	0.51	10.20
140-150	0.61	12.20
190-200	0.69	13.80
240-260	0.78	15.60

Also assumes: loading and unloading = 1.60/ton
dewatering = 15.00/ton

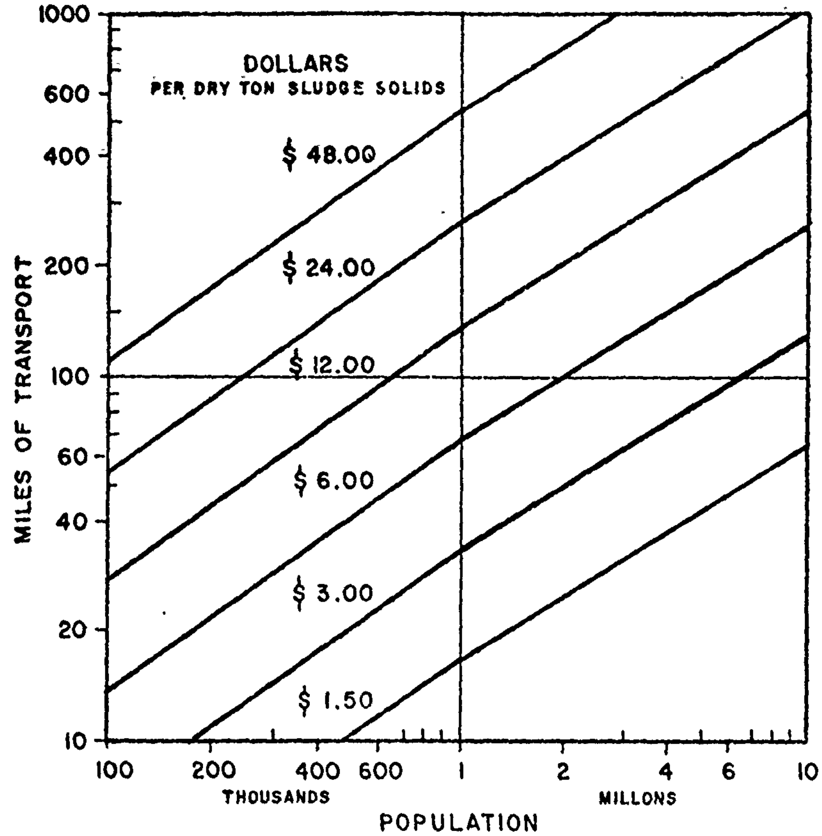
3/ For sludge at 10% solids, standard freight classifications are:

Distance (miles)	Rate ($/cwt)	Cost ($/ton)
45-50	0.69	12.80
95-100	0.90	18.00
140-150	1.07	21.40
190-200	1.20	24.00
240-250	1.36	27.20

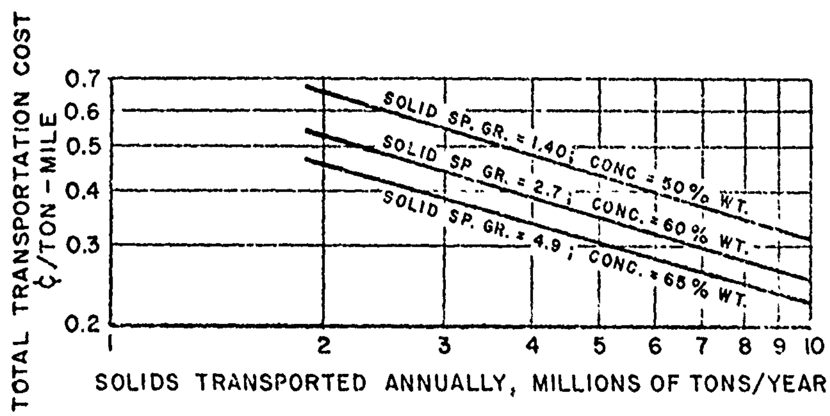
Also assumes: loading and unloading = 1.00/ton
concentration to 10% solids = 2.00/ton (dry)

4/ Escalated from 1968 cost base by a factor of 1.67

5/ Escalated from 1970 cost base by a factor of 1.44



(A) TRANSPORTATION COSTS PER DRY TON SLUDGE SOLIDS.



(B) SLURRY TRANSPORTATION COSTS VARIATIONS WITH SOLIDS SPECIFIC GRAVITY AND AMOUNTS MOVED.

(Ref. 150, Fig. 1 & 16)

SLURRY AND PIPELINE TRANSPORT COSTS

Figure III-E-9

a) High rate digestion tanks for thickened sludge.

b) Two storage tanks for digested sludge resulting in 4 percent solids concentration.

c) Centrifuge installed to concentrate to 9 percent solids — expected to reduce the 80 barging trips per year to about 50 trips.

Barging facilities consist of:

a) 200-foot docking space adjacent to plant.

b) Two 10-inch flexible loading hoses from a 12-inch feeder line for rapid loading.

c) One 4-inch hose for delayed loading.

d) The barge having 1525 tons (50,000 cubic feet) of sludge capacity and 75 tons of grit capacity. Grit hoppers are separate.

Costs for the Westchester County operation are given below:

a) Capital Costs:

Capital costs for sludge disposal facilities (not including thickening, digestion and storage tanks, but including dock, 1960-1963)	=	$245,300
Capital cost of barge (1960)	=	249,200
Total capital cost for sludge disposal	=	$494,500

b) Annual Costs:

Amortization (30 years) and interest (3%)	=	$ 23,900
Operating cost for 1963	=	78,998
Total annual cost for sludge disposal	=	$102,898

c) Cost per ton dry solids = $\frac{102,898}{3,825}$ = \$26.90
$0.50/ton-mile (1963) $1.00/ton-mile (1972)

These data indicate that operation and maintenance costs comprise about 78 percent of the total annual costs.

2. Middlesex County Sewerage Authority (17 municipalities). The Authority contracts for barging sludge to the sea. Sludge handling facilities consist of:

a) Two sludge thickeners of 6-3/4 hours detention time capacity at a 2 mgd plant.

b) Four steel storage tanks of 800,000 gallon capacity each.

c) Two 1500-foot, 18 inch C.I. pipelines from storage tanks to dock.

Dock facilities consist of two 12-inch hose connections on ends of 18-inch sludge lines. Hoses are handled by mechanical equipment at the dock. Barges make a trip every two weeks. The Authority's 1963 barging contract was for a price of $0.68 per ton. This would be about $1.36 in 1972.

A report by Ditmars & Carmichael in 1964 on sludge handling for the Town of Orangetown, New York is summarized by the following.

Only primary settled raw sludge is discussed in this report. Transportation from primary tanks to the wharf by pipeline is discussed with the general requirements of the proposed installation, which are that the raw sludge have a 4 to 5 percent concentration of solids in the pipeline and that it be thickened at the wharf to 8 to 10 percent solids and stored there for loading onto a barge. The following facilities were recommended:

a) At the treatment plant:

1) Raw sludge pumps

2) Means for adjusting the rate of sludge withdrawal from the settling tanks to produce a relatively high solids content (4 to 5 percent).

3) Storage with controls to receive sludge intermittently drawn from the settling tanks and to discharge it at an even rate.

b) Between the plant and the wharf:

1) A pipeline for conveying the sludge from the plant to the wharf.

2) A pipeline to return the excess water from the thickener to the treatment plant.

c) At the end of the pier:

1) Two raw sludge pumps
2) Two thickening tanks
3) Two thickening sludge pumps
4) Two return liquid pumps
5) Two steel storage tanks of total volume equal to the barge capacity
6) Two pumps for loading the barge
7) One river-water pump
8) Dock and fenders, davits, etc.
9) Electric power service
10) Operating building
11) Interconnecting piping, controls, roads and appurtenances (loading time about 6 to 8 hours)

d) Barge: both 1600 ton and 1000 ton barges were considered.

Costs for the Middlesex County operation are given below:

a) Capital Costs: (1964 shore installation for 7000 ton barge)

Additions to plant		$ 14,000
Piping - plant to pier		190,500
Facilities at pier		658,000
Total construction cost	=	$862,500
20% contingencies		172,500
Total capital cost		$1,035,000
Estimated annual capital cost (20 years @ 3%)	=	$69,550

b) Annual Costs:

Heat	$ 225
Telephone	150
Repairs	2,500
Painting	2,500
Taxes	8,000
Road maintenance	250
Electrical	2,885
Labor	10,400
Barging 1/	54,720
Total	$ 81,630
Plus 5% contingencies	4,080
	$85,710
Amortization	69,550
Total Annual Cost	$155,260

c) Cost per dry ton solids = $\frac{155,260}{5,840}$ = $26.60
Basis: Estimate 1975 dry solids, 16 tons/day, 5840 tons/year
For 55 mile haul: $0.484/ton-mile

These data indicate that operation and maintenance costs comprise about 55 percent of the total annual cost.

A comparative cost summary is given in Table III-E-4 for incineration, digestion and barging to sea for four alternative capacities. Figure III-E-10 shows the dock facilities proposed for the Town of Orangetown, New York.

7 - Environmental Evaluations of Transportation of Sludge

There should be no detrimental environmental impacts by the transportation of sludge by any of the modes discussed if proper care is exercised and the general controls outlined below are followed. Their addition to current traffic loads should cause no significant adverse impact.

a. Truck Transport

1. For sludge transported in a solid state (20-30% solids):

1/ Towing tug @ $750 per 110 mile round trip. 7000 ton barge towing cost @ $0.11/ton @ 8% solids

Table III-E-5

COMPARATIVE COST

COST PER TON OF DRY SOLIDS

PROCESS		1967 Alternate 1 Orangetown	1967 Alternate 2 Orangetown Lederle	1967 Alternate 3 Orangetown County	1967 Alternate 4 Orangetown Lederle County	1975 Alternate 1 Orangetown	1975 Alternate 2 Orangetown Lederle	1975 Alternate 3 Orangetown County	1975 Alternate 4 Orangetown Lederle County
Multiple Hearth Incineration	Capital	17.80	6.94	13.89	7.66	7.12	4.95	5.05	4.66
	Operating	23.50	18.36	19.61	18.44	18.68	18.95	15.85	17.94
	Total	$ 41.30	$ 25.30	$ 33.50	$ 26.10	$ 25.80	$ 23.90	$ 20.90	$ 22.60
FS Disposal System	Capital	25.35	11.14	21.95	10.72	10.13	7.92	7.93	6.52
	Operating	20.10	17.17	17.30	16.83	17.61	18.14	14.89	17.41
	Total	$ 45.45	$ 28.31	$ 39.25	$ 27.55	$ 27.74	$ 26.06	$ 22.82	$ 23.93
Zimpro	Capital	31.73	14.93	30.58	16.09	12.67	10.62	11.05	9.79
	Operating	14.28	10.01	12.15	10.07	12.33	10.03	10.09	8.27
	Total	$ 46.01	$ 24.94	$ 42.73	$ 26.16	$ 25.00	$ 20.65	$ 21.14	$ 18.06
Anaerobic Digestion	Capital	114.46	34.92	66.08	36.59	45.72	24.83	23.87	22.27
	Operating	17.47	10.48	14.08	10.10	13.68	10.66	11.40	8.86
	Total	$ 131.93	$ 45.40	$ 80.16	$ 46.69	$ 59.40	$ 35.49	$ 35.27	$ 31.13
Barging 1600 Ton Barge	Capital	30.37	10.01	22.28	9.16	12.13	7.12	8.05	5.57
	Operating	31.54	20.52	27.73	20.57	21.30	18.76	19.27	18.20
	Total	$ 61.91	$ 30.53	$ 50.01	$ 29.73	$ 33.43	$ 25.88	$ 27.32	$ 23.77
Barging [illegible]00 Ton Barge	Capital	47.94	14.70	32.96	12.97	19.15	10.45	11.91	7.89
	Operating	26.95	15.90	23.13	15.98	16.70	14.17	14.68	13.61
	Total	$ 74.89	$ 30.60	$ 56.09	$ 28.95	$ 35.85	$ 24.62	$ 26.59	$ 21.50

(Reference 162, Table 15)

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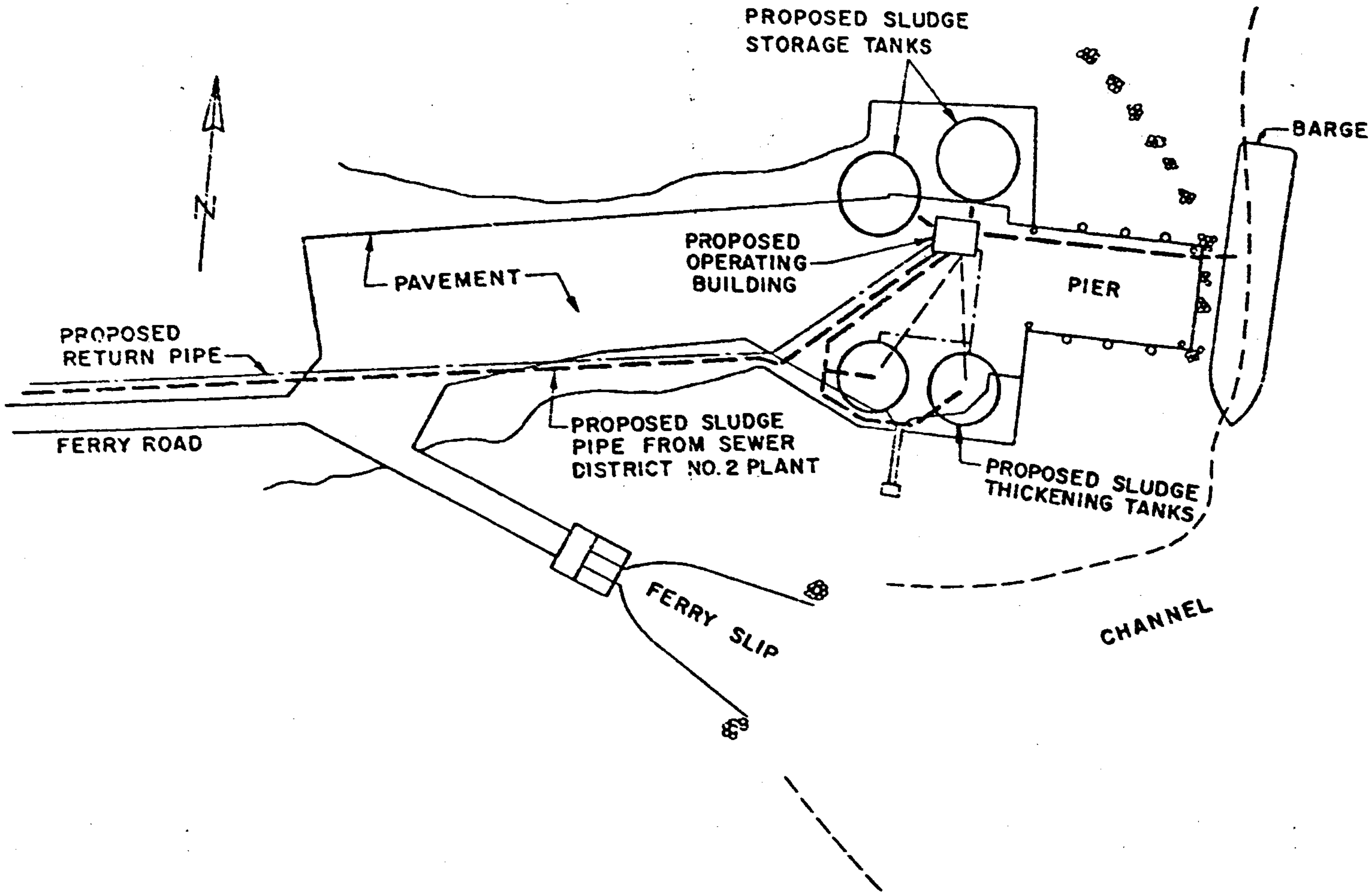


PLAN OF LOADING DOCK AND STORAGE FACILITIES

Figure III-E-10

(Ref. 162, Plate 3)

a) The truck load should be covered.
b) The truck body should be tight to avoid spillage along the route of travel.
c) Dump sites should be maintained in a neat and clean condition.
d) Dumped material should be graded level, compacted and covered with earth if necessary to avoid a nuisance.

2. For sludge transported in a liquid state (less than 10% solids):

a) A closed tank should be used.
b) Dump sites should be maintained in a neat and clean condition.
c) Spread should be uniform on the area.

b. Railroad Transport

1. For sludge transported in a solid state (20-30% solids):

a) The open cars can be covered if desired.
b) The cars should be tight to avoid spillage.
c) Loading and unloading facilities should be kept in a neat and clean condition.
d) Loading and unloading operations should be carefully performed to eliminate spillage or other nuisance.

2. For sludge transported in a liquid state (less than 10% solids):

a) A closed tank should be used.
b) Transfer to and from the tank cars should be in closed piping.
c) Occasional maintenance and cleaning should be done at an approved location and in a manner avoiding damage to the environment.

c. Barge Transport

1. For sludge transported in a solid state (20-30% solids):

a) The barge should be covered.
b) The barge should be tight to avoid spillage and leakage.
c) Unloading facilities should be maintained in a neat and clean condition.
d) Care should be taken during loading and unloading to avoid spillage.

2. For sludge transported in a liquid state (less than 10% solids):

a) A closed tank should be used.
b) Transfer to and from barge should be by pumps and piping.
c) Occasional maintenance and cleaning operations should be done in place and manner to avoid pollution of the waters.

d. Pipeline Transport

Since pipelines will be constructed along existing rights-of-way, roads, etc., or on their own rights-of-way or easements and will be buried beneath the surface of the ground, there should be no detrimental effects on the environment with carefully managed installation and proper maintenance.

8 - Summary

Four basic modes of transport of wastewater sludges and other residual solids are currently being used. These and associated costs are summarized in the following:

1) Truck Transport, for haul up to 50 miles in radius from treatment plants. Applicable to all types of residual solids, whether "wet", thickened, dewatered, dried, or incinerated. Cost appears to range from about $0.80 to $2.00 per dry ton-mile.

2) Railroad Transport, for haul between 50 to 200 miles or more from treatment plants. Applicable to all types of residual solids, whether "wet," thickened, dewatered, dried, or incinerated; particularly suited to organic and lime sludges. Cost appears to range from about $0.60 to $6.00 per dry ton-mile.

3) Barge Transport, for haul between 20 to 150 miles from treatment plants. Applicable to all types of residual solids with very probable exception of toxic solids; particularly suited to organic and lime sludges in the liquid, thickened, or dewatered state. Costs appear to range from about $0.15 to $1.50 per dry ton-mile.

4) Pipeline Transport, for haul between 100 feet up to 200 miles or more. Applicable primarily to organic and lime sludges in concentrations up to 7 percent total dry solids (Moyno type pumps being able to handle dewateredsludges up to 20 percent total dry solids for short distances;) applicable to mascerated screenings, skimmings, and regeneration solids for short in-plant distances. Costs appear to range from about $0.11 to $1.02 per dry ton-mile.

Transportation costs are summarized in Volume III, Table III-E-4. The relative costs of several of the major methods of disposal in relation to transportation requirements are summarized in Figures III-E-6, 7, and 8 and Table III-E-3. These indicate the strong competitive position of land application by irrigation, particularly for major population centers and for distances up to 100 miles.

F. SLUDGE RECYCLING

F. SLUDGE RECYCLING

1 - General

Of the wastewater sludges and residual solids previously noted, two components, the Toxic Solids and Regeneration Solids, are not considered reusable components. 1/ Usuable components of the five sludge types are:

a. Grit - Glass, sand, gravel and metal.

b. Organic Solids - Mixture of primary and secondary sedimentation tank sludge.

c. Oil and Grease - Vegetable and animal fat, petroleum oil and solvents, and synthetic oils.

d. Screenings - Rags, wood, plastics, metal, rocks and large organics.

e. Lime Sludges - Calcium Oxide and phosphorous.

A partial listing of the end products and their uses is as follows:

a. Grit, which has been washed or otherwise treated to remove organics which could putrify and give off noxious odors, is a suitable landfill material. Grit can also be included in compost.

b. Organic solids must be partially dewatered to permit handling and for mixing with other organics in composting.

c. Oils and grease must be skimmed and dewatered. Animal, vegetable and petroleum fractions can be burned as fuel. Also, where these fats and oils are put into digester tanks, the gas produced can be used as a fuel with a heating value of approximately 600 BTU per cubic foot.

1/ General references for this Technical Appendix III Chapter include: 6, 16, 17, 19-24, 34, 38, 41, 42, 46, 48-63, 114, 120, 126, 195, and 214.

d. Screenings contain combustible items which can be incinerated. The screenings can be passed over sorting belts where manually or mechanically salvageable items are removed. The value of salvage seldom recovers the cost of sorting and separation.

e. Lime sludges contain calcium and phosphorous which can be recovered and reused. The sludge is dewatered and then used for fill or as an addition in composting. Further processing of lime sludge by heat results in recalcining the lime sludge to calcium oxide, which is reusable. The phosphates can be reused as agricultural fertilizer components.

2 - Product Value and Use

Solids products of wastewater treatment have but limited value for reuse. Only the sociologic value of reuse justifies reclamation.

Grit, incinerator ash, and compost may be used as fill for land reclamation but more suitable materials are usually available.

Skimmings may be separated by solvent or distillation processes into organics, animal and vegetable oils, and petroleum products.

However, handling, storage, and processing costs are high. Although there was an export market for reclaimed animal and vegetable oils twenty years ago, contamination and the reduced use of soap for detergents have eliminated the market.

While compost has values for agricultural use not found in commercial fertilizers, the increased composting of crop and animal wastes for disposal competes directly with sludge composting.

Farm and feed lot composts contain between two to three times the fertilizer values of wastewater sludge compost and generally set maximum market prices. The current bulk price of compost in California ranges from $2 to $6 per cubic yard.

3 - Composting

The Composting Process. Composting is the man-managed microbiological decomposition, digestion, degradation or stabilization

of the carbon and nitrogen components of relatively dry organic materials (40 to 70 percent moisture) by aerobic or combined aerobic-anaerobic (facultative) biochemical processes which result in the end products of carbon dioxide, water, mineralized organics, and humus. Humus is a substantially stabilized organic material with properties very much like those of the organic fraction of topsoil. Composting consists of two basic types: (1) the older and more ancient combined aerobic and facultative mesophilic (60 - 110° F) composting; and (2) the modern and much faster aerobic thermophilic (110 - 180° F) composting. Composting, thus involves processes very similar to other microbiological biochemical oxidation processes, particularly to those which take place in more dilute slurries or in suspended or dissolved organic materials involved in various wastewater and sludge treatment processes. Anaerobic composting may however, utilize fungi not present in aerobic processes. Therefore the end products have quite different physical characteristics, particularly with respect to the humus-like material associated with composting processes.

This stabilization will occur in nature where the material is mixed with soil and bacterial action takes place, but it may require periods up to several years if all factors are not suitable. Forest leaves, by contract, may stabilize in a matter of months. Under controlled conditions, stabilization can be accomplished in a matter of days. The important factors are aeration, moisture, particle size, temperature, chemical composition and time. Aerobic composting is more rapid than anaerobic composting and does not lose nitrogen through formation of ammonia nor does it produce odorous materials.

For optimum efficiency and preservation of nutrient values, aerobic composting should be used. Some relatively simple field composting methods such as the Tillo process have been effective. Other processes include field methods with forced ventilation and completely mechanized processes with all significant factors controlled such as the Dano, Frazier, Earp-Thomas, American Composter, and Snell processes.

Compost material will undergo volume reduction up to 30 percent depending on initial carbon-nitrogen (C/N) ratios. Satisfactory composting can be carried out with an initial C/N ratio between 70 and 30. Above a C/N ratio of 70, excessive time is required for composting and below a C/N ratio of 30 nitrogen may be lost to the atmosphere. Initial moisture of the composting mixture should be between 40 to 60 percent. However, effective moisture can be reduced and controlled by recycling finished compost back into the initial mixture.

Finished compost is usually dark grey or dark brown in color, neutral or earthy in odor, with a C/N ratio of 20 or less, neutral in pH, and has a moisture content of 20 to 50 percent. Composting time is generally dependent on the C/N ratio although the form of the carbon is important. For mixed wastes it has been found that for an initial C/N ratio of 20, 10 days are required; for a C/N of 20 to 50, about 14 days; and for a C/N of 70 to 80, at least 21 days are required. Best activity takes place above a pH of 7, a pH of 8 will inhibit fungus development which may give rise to odors and inhibit bacterial action.

Composting applicability. Grit, organic solids, wood, rags, animal fats and lime sludges produced by wastewater treatment plants can all be used in varying amounts in composting. Petroleum, oil and grease, toxic solids and regeneration solids are not suitable for inclusion in composting.

Composting has the following advantages:

a. Worn out agricultural soils can be rebuilt by using compost and other suitable minerals.

b. Composted material can be used as fill.

c. Many industrial wastes can be disposed of by means of composting.

d. A well located composting plant can reduce the hauling distance to an acceptable disposal area.

e. Flexible operation permits overload of the plant for several days since the operation is usually not on a 24-hour basis.

Composting has the following disadvantages:

a. Capital and operating costs for most processes are relatively high.

b. Site procurement is difficult because most neighborhoods consider a waste disposal plant undesirable.

No composting process, except for the Tillo process, and that used in the 1968-69 Eimco Corp. - U.S. Public Health Service Demonstration Project (Ref. 114,) was developed for use specifically with wastewater sludge. Most of the other processes, however, have used wastewater sludges mixed with garbage and refuse. While the

other processes can probably be adapted to use with wastewater sludge., it appears probable that some waste cellulose material must be added both to facilitate operation and to avoid nitrogen loss. The composting processes being developed for farm manure show promise for application to wastewater sludge.

Wastewater sludges can approximate the final compost C/N ratio of 20., depending on the degree of digestion and industrial waste content. At least one mechanical composting process reported composting wastewater sludge within four hours. Other data indicate that only some stabilization may have occurred. Complete composting should take ten days.

If cellulose material is mixed with sludges prior to composting, two benefits can be realized. Sludge of pumpable consistency can be reduced to a suitable moisture content for composting and the carbon-nitrogen ratio can be increased to insure avoiding nitrogen loss. Several sources of cellulose materials can be utilized. Leaf rakings and street sweepings have been successfully used as have sawdust, rice hulls, and waste paper although the carbon is less readily available in the latter materials and composting time is increased. Peat moss has been found to be the best because it has the highest moisture capacity, composts rapidly, and produces the highest quality compost material.

<u>Types of Field Composting</u>.

(1) Flood-drying Windrowing: Cellulose material is spread in a layer and flooded with liquid sewage sludge. After absorption of moisture the material is tilled with roto-tiller or harrow. After drying to 60 percent moisture or less, the area is reflooded with sludge. After repeated floodings and tilling to the depth of the bed the material is windrowed, allowed to compost at least a week and then re-windrowed. After the third windrowing the composting is usually complete.

(2) Ordinary Windrowing: Compost material is mixed and piled in long rows and may be side cast for mixing. Piles retain heat but also do not pack down and thus allow air movement. The addition of waste cellulose material (leaves, rice hulls, bagasse, etc.) enhances porosity and thus facilitates air movement.

(3) Modified or Forced-air Windrowing: Where the material packs or does not have enough filler material to promote natural ventilation, a forced air system is helpful.

(4) Area Composting: Compost material is piled to a uniform depth in a definite area. Air is introduced through a porous floor. Seeding and turning may be employed. This method takes 10 to 14 days and requires one-third the space required for windrow composting. This type of composting has been successful with farm manure.

. Field Composting - Windrows and Piles. Windrows and piles can take on several configurations. Figure III-F-1 (A) shows the basic windrow which is placed on fairly level land. The 4 to 6 foot height varies depending on the moisture of the raw materials. The pile material acts as insulation to hold the generated heat in the pile. The pile is turned in on itself to provide passages for aeration and to control moisture. This turning and mixing places pathogens, fly larve and insect eggs, which may have been on the cool surfaces of the pile, inside where temperatures of 160 to 170° F. will destroy the organisms.

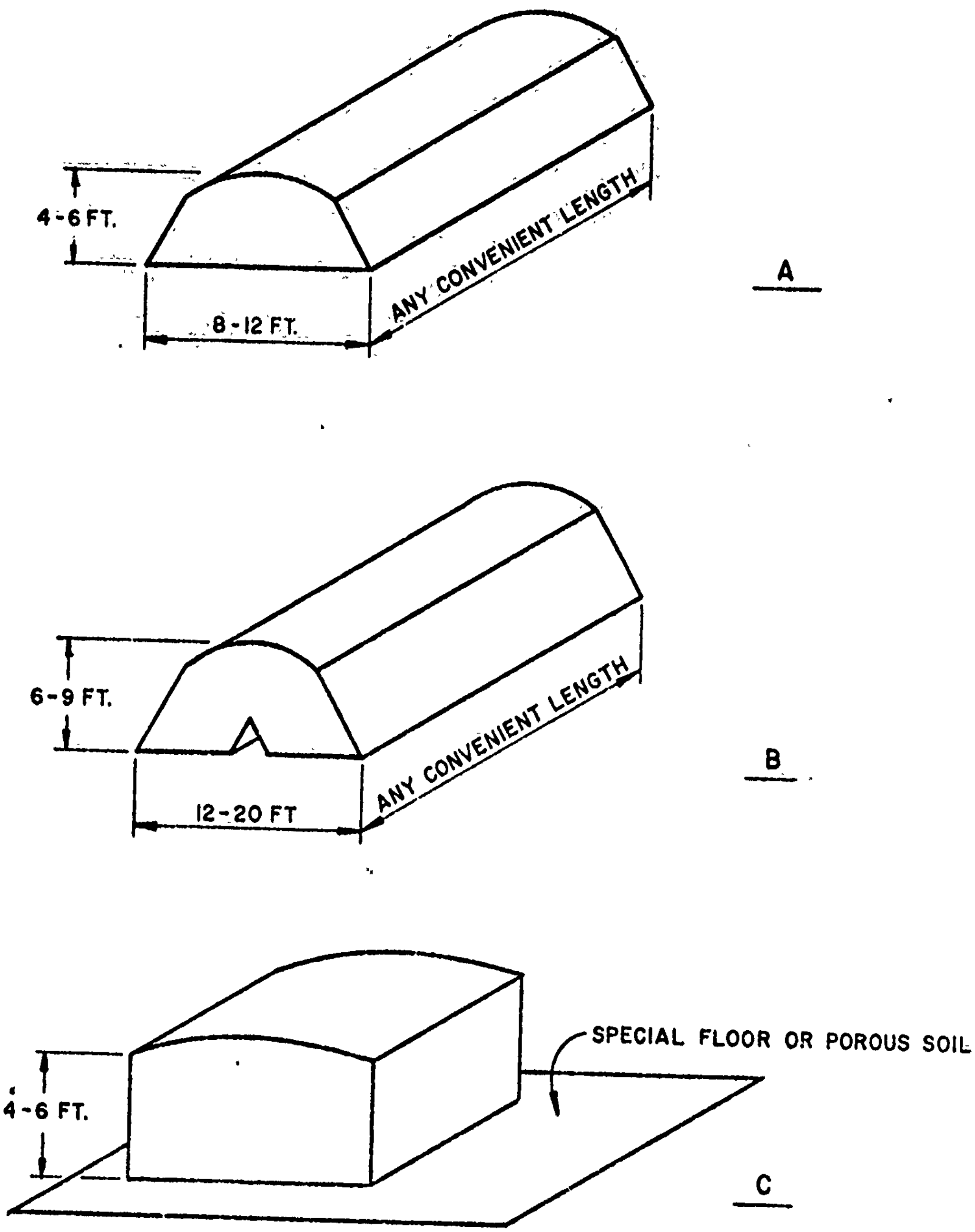
In some instances mechanical aeration by ducted air discharges into the piles is provided to speed the process. An alternative to fans is shown in Figure III-F-1 (B) in which an internal passage is built inside the windrow so that natural ventilation can be obtained from both outside and inside the pile.

Figure III-F-1 (C) indicates an area composting facility. While the windrow can be any length, the area type pile is designed to take less space than the windrow. However, the process requires controlled amounts of air which pass up through a special floor or porous soil bed. Turning and seeding are used to speed the process.

Mechanical Composting. A number of proprietary systems of mechanical composting are available. (See Figures III-F-2, 3, 4) All incorporate grinding and/or separation which are not needed for sludges. In composting sewage sludges, unless municipal refuse and garbage is incorporated, the usual segregation and grinding of inflow would be omitted. Composting takes place under controlled temperature, moisture, mixing and aeration conditions in a reaction vessel and is subsequently discharged for aging and storage. Temperature in the reaction vessel is usually maintained between 140° and 160° F which, in addition to accelerating stabilization, inactivates pathogens.

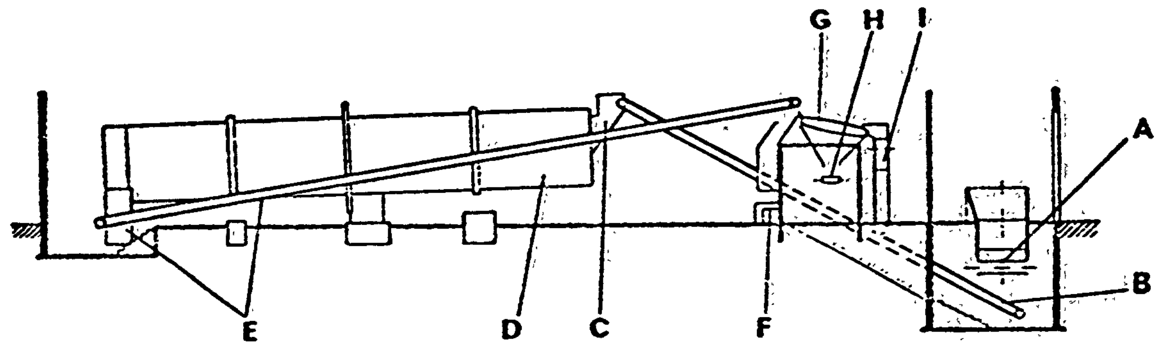
No known plants now compost wastewater sludge but a number compost it with cellulosic solid wastes. It is probable that addition of some cellulose material may be required for satisfactory composting.

Reaction vessels used have been vertical or horizontal, towers, or combinations of these. Mechanical composting has been accomplished



WINDROWS AND PILES

Figure III-F-1



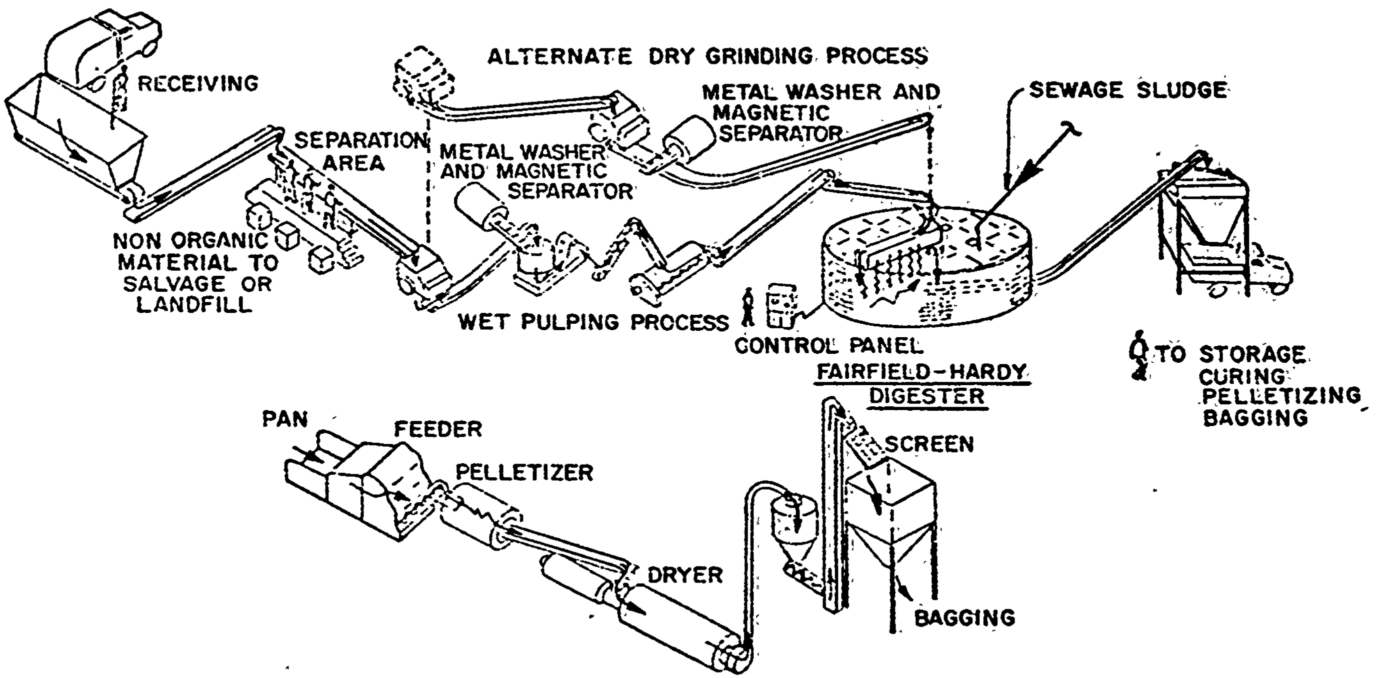
A = *receiving hopper*
B = *conveyor belt for crude refuse*
C = *device for feeding material into Bio-stabilizer*
D = *Bio-stabilizer*
E = *conveyor belts for transferring material from Bio-stabilizer to screen*
F = *hopper and equipment for cans and scrap metal*
G = *screen*
H = *conveyor belt for taking away screened compost*
I = *chute for tailings from screen*

At this plant, 20 tons of refuse, with sewage sludge added, are processed per day.

DIAGRAM SHOWING COMPOSTING PROCESS IN A 25 TON-A-DAY DANO "BIO-STABILIZER" PLANT AT EDINBURGH, SCOTLAND

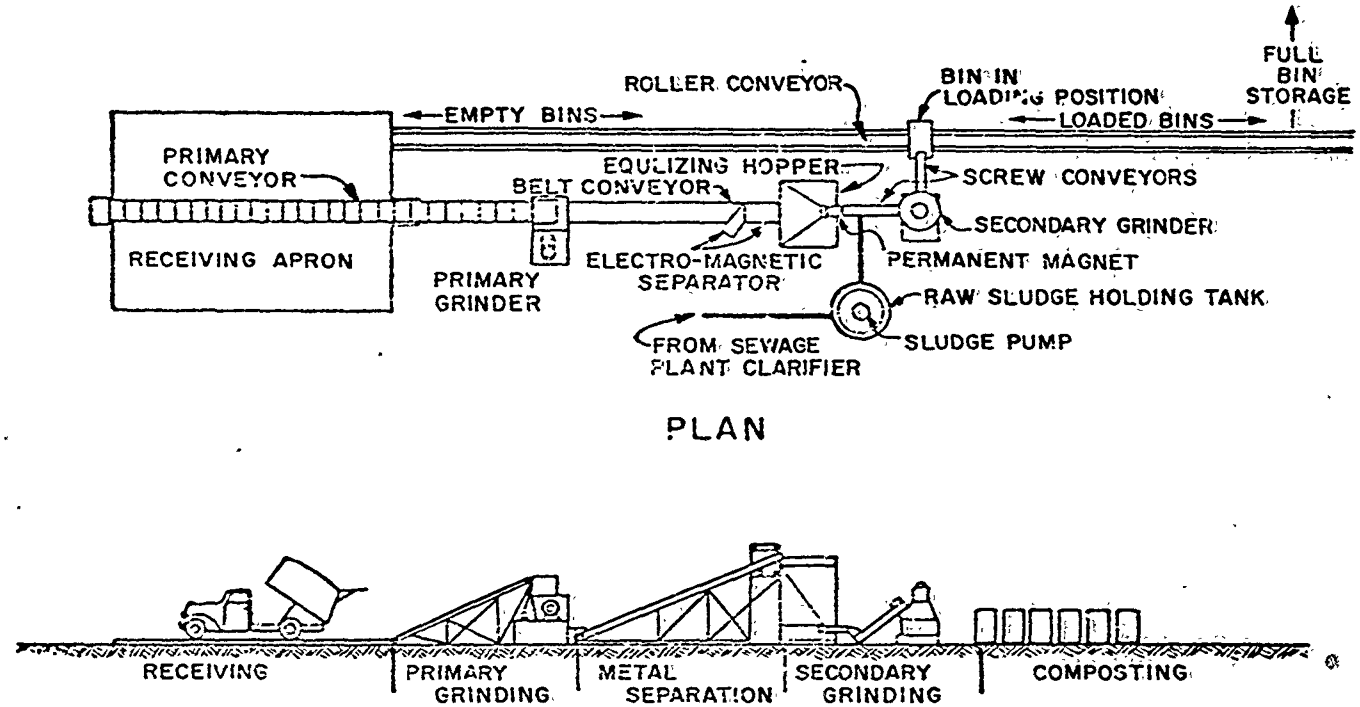
Figure III-F-2

(Ref. 16, Fig. 120)



FLOW DIAGRAM OF 100 TON PER DAY
FAIRFIELD - HARDY DISPOSAL SYSTEM

Figure III - F-3
(Ref. 214)



SCHEMATIC LAYOUT OF DEMONSTRATION COMPOST PLANT AT CHANDLER, ARIZONA, OPERATED BY UNITED STATES PUBLIC HEALTH SERVICE.

Figure III - F-4

(Ref. 16, Fig. 126)

in from one to seven days depending on characteristics of feed material. Stabilization is usually accomplished in the reaction vessels with final composting in windrow storage.

The Eimco Corp. - U.S. Public Health Service demonstration project was developed specifically to test mechanical composting on municipal wastewater sludges by themselves (Ref. 114.) The operation, illustrated in Figure III-F-5, involved three phases; dewatering of the wastewater sludge, mechanical composting, and final curing. The only organic materials added to the sludge were polymers to enhance mechanical dewatering, reportedly at a rate where the polymers constituted 1.6 percent of the dewatered sludge solids. The largest addition of chemical conditioners was for lime, it amounting to 15.5 percent of the dewatered sludge solids. Average percentage reductions from the dewatered sludge solids to the final compost were as follows:

1) 87 percent in moisture, moisture content going from an average of 72 percent in the dewatered sludge feed to 26 percent in the final compost,

2) 73 percent in volume and weight, the range being 60 to 85 percent, and

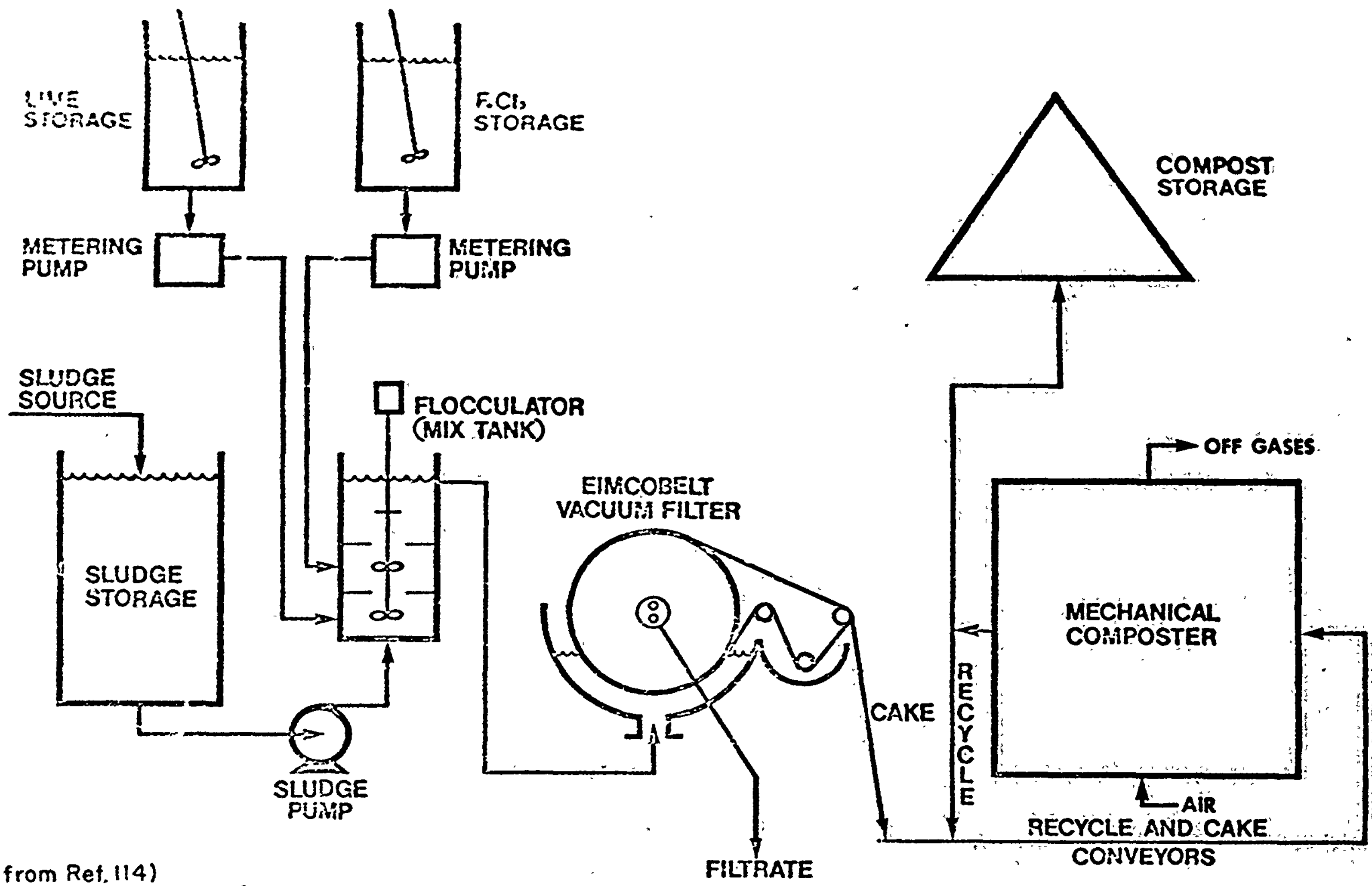
3) 30 percent in solids.

Typically, 100 pounds of dewatered raw wastewater sludge (containing 28 pounds of solids) would produce 26.5 pounds of compost (containing 19.6 pounds of solids, 8.8 pounds or 45 percent being volatile solids.) Observed bulk density of the compost was 48 pounds per cubic foot. The final compost had a fertilizer value approximating that of cattle manure; total nitrogen averaging 2.21 percent of total dry solids, phosphorous as P_2O_5 averaging 2.16 percent, potassium as K_2O averaging 0.27 percent.

Anaerobic Composting. Composting may be accomplished by anaerobic as well as aerobic means. Several such processes have been used in Europe but have found little acceptance due to severe odor problems and high putrifactive organic content in drainage waters.

The Becarri and Verdier processes are completely anaerobic while the Indore process is a combined aerobic-anaerobic process.

Composting Costs. The cost of various composting methods applied to wastewater sludges cannot be readily estimated because only



(from Ref. 114)

PROCESS FOR COMPOSTING DEWATERED SEWAGE SLUDGE

EIMCO CORP. - U.S. PUBLIC HEALTH SERVICE DEMONSTRATION PROJECT

Figure III-F-5

one process has been used specifically on such solids. In addition, most of the processes have seen limited application, mostly in plants of smaller capacities. While elimination of segregation and grinding facilities needed for refuse composting would reduce costs, supply and handling of cellulose material and blending for moisture control will increase costs.

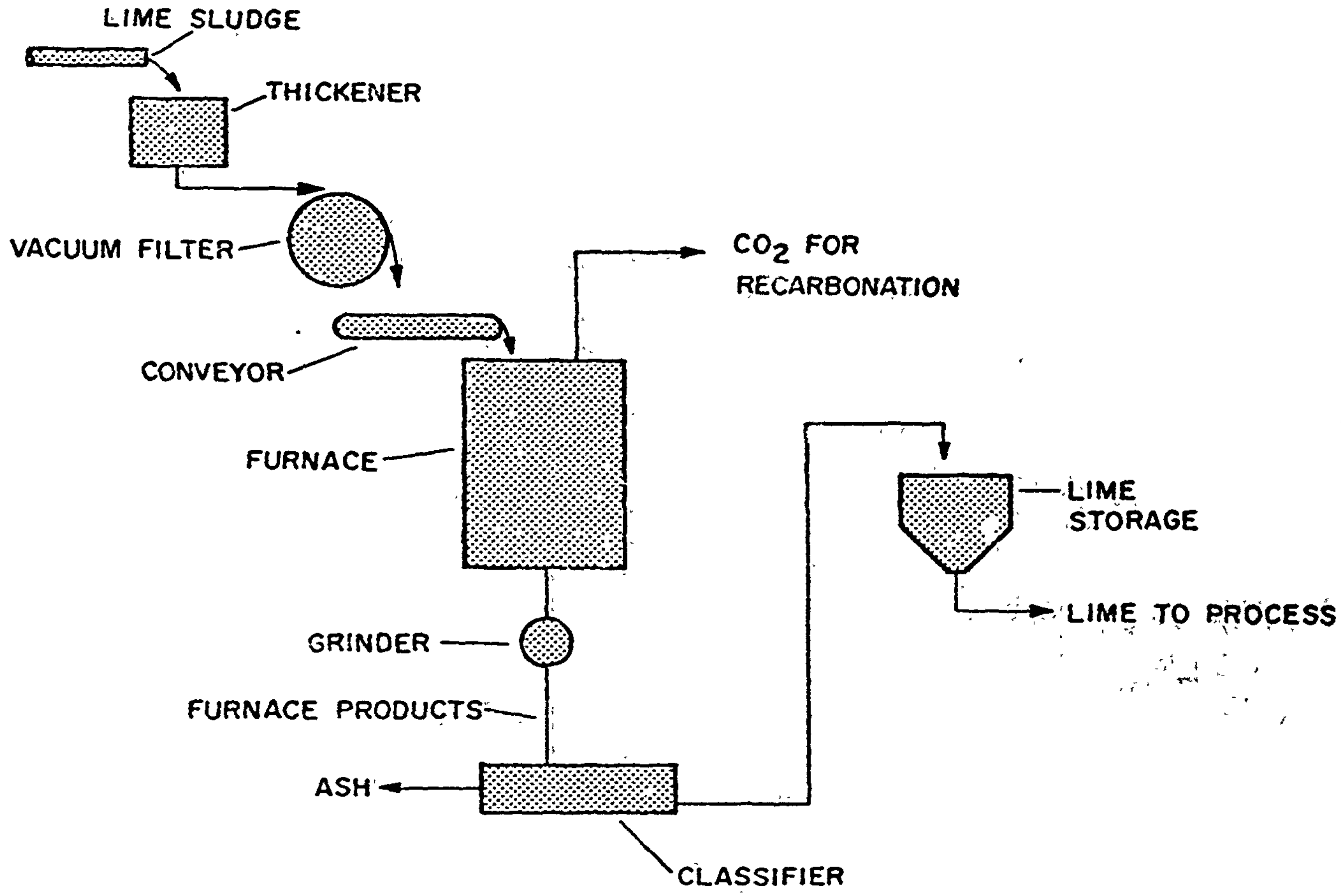
Mechanical refuse composting costs between \$30 and \$60 per ton of compost (excluding land costs), based on recent estimates. Field methods cost between \$5 and \$30 per ton. Estimates of cost reductions for scale cannot be realistically made at this time. The only specifically relevant cost data is for the Tillo field compost process, which has an indicated cost of \$5 to \$6 per ton of compost. These values indicate a cost for field composting sludge ranging from \$15 to \$25 per ton of wastewater sludge solids on a dry weight basis. It is estimated that other composting methods will cost from \$50 to \$250 per ton of wastewater solids on a dry weight basis. Because of limited experience in composting plants in sizes above 100 ton per day capacity, it is expected that plants of large capacity will require multiple units resulting in little economics in scale.

4 - Recalcination of Lime Sludges

Lime treatment systems discharge sludge with recoverable quantities of spent lime. The sludge constituents, as indicated in Table III-F-1a, can be thermally processed in the customary sludge incineration furnaces (i.e., multiple-hearths, rotary kilns, etc.) at temperatures between 1500-1900°F. This recalcining temperature range is somewhat higher than the normal incineration range of 1100-1600°F. The lower limits indicate the temperatures at which drying takes place while the upper limits indicate the combustion temperature levels. Recalcination requires higher drying temperature levels in order to prevent the slow drying of the $CaCO_3$ and hence the caking and clinker formation associated with this slower drying. This higher temperature range will most likely require additional auxilliary fuel and therefore higher operating costs. In the thermal processing of recalcination, the organic and inorganic volatilizables are reduced to zero. Spent lime is recalcined to CaO; $Mg(OH)_2$ is converted to MgO; and $Ca_5OH(PO_4)_3$ passes through relatively unchanged. Inerts such as grit and other non-volatile materials can be removed by air classifiers.

A typical recalcination process is illustrated in Figure III-F-6. In dewatering for recalcination, centrifuges have the advantage over vacuum filters in being able to separate phosphate sludge ("phosphate calcium", calcium hydroxyapatite - $Ca_5OH(PO_4)_3$) from $CaCO_3$. (Ref. 195.) The $CaCO_3$ can then be recalcined while the phosphate sludge can be incinerated.

A typical analysis of furnace feed and product is shown in Table III-F-1.



TYPICAL RECALCINATION PROCESS FOR RECOVERY OF LIME FROM SEWAGE SLUDGE

Figure III-F-6

Table III-F-1

a. Furnace Feed

CaO	0%
Inerts (including MgO)	17%
$Mg(OH)_2$	1%
$Ca_5OH(PO_4)_3$	17%
Volatiles	12%
$CaCO_3$	47%
MgO	6%

b. Furnace Product

CaO	35%
Inerts (including MgO)	24%
$Mg(OH)_2$	0%
$Ca_5OH(PO_4)_3$	24%
Volatiles	0%
$CaCO_3$	7%
MgO	10%

The furnace discharge is cooled and passed through a grinder. CaO is separated in an air classifier and then conveyed to storage. Inerts and remaining ash can be used for fill or incorporated in compost.

G. RESIDUAL SOLIDS DISPOSAL BY LAND APPLICATIONS

G. DISPOSAL OF RESIDUAL WASTEWATER SOLIDS BY LAND APPLICATIONS

1 - General

Land application specifically refers herein to the spreading or placing of wastewater sludges and other residual solids on or under the land. It includes the following range of methods:

a) Sub-surface Disposal
   - Burial and Sanitary Landfilling
   - Deep Well Injection

b) Surface Disposal
   - Landfilling and Stockpiling
   - Dry Surface Spreading
   - Wet Surface Spreading - Irrigation

Burial is a method of disposing of materials consisting primarily in placing them under a shallow earth cover, either in natural or man-made depressions or by such crop cultivation derived methods as discing, and their being placed in deeper underground natural or man-made cavities. Sanitary landfilling is, strictly speaking, a form of burial. The net result is a changed topography and changed elevations of the area being "filled" while burial, strictly speaking, implies no deliberate or significant changes in topography or elevations. Primarily a method employed in solid wastes or refuse disposal, it consists of the systematic deposition of these waste materials in natural or man-made depressions and subsequently covering the material with compacted earth or other materials on a periodic basis, usually once a day (Refs. 16, 17, 19, 23, 180, 181.) In combination with various degrees of volume reduction, burial and sanitary landfilling is applicable to all types of residual solids. With lime sludges, burial of recalcination ash is associated with recycling of recovered lime.

Deep well injection is a method of land disposal which involves the underground disposal of wastes by their being pumped into suitable deep subsurface strata (Ref. 154). It is particularly suited to isolatable toxic solids (ie., radio-active wastes) and to hard-to-treat organic and chemical sludges of primarily industrial origin.

Landfilling, stockpiling or open dumping is a method of disposing of waste materials by means of deposition within reasonably well defined areas or in natural depressions without the subsequent placement of cover materials. In the case of landfilling proper, it is associated with significant changes in topography or elevations. This method of surface disposal is particularly suited to washed, incinerated, and compacted grit and incinerated, composted, or very well stabilized organic sludges (including any grit and regeneration solids inclusions.) The method constitutes a form of recycling; major sub-types are lagooning and mass fills.

Land Application by Dry Surface Spreading involves the distribution of dried sludges over the surface of the earth with the net result of no bulky depositions in relatively confined areas. The spreading involves principally agricultural lands or landscaping projects. This method is restricted to washed, incinerated, and composted grit; digested and dried, filtered and heat dried, composted, and incinerated organic sludges; and certain incinerated industrial waste chemical sludges. The method constitutes another group of recycling "disposal" methods; major uses: for walks and roadways, for inclusion in paving materials and construction concrete, for soil additives and fertilization.

Land Application by Wet Surface spreading - irrigation involves the distribution of wet sludges over the land surface with the net result of no significant or persistent ponding. The method is restricted to wet digested or to slurried and composted organic sludges. It constitutes a major recycling "disposal" method; the sludges serve as soil conditioners and fertilizers for agricultural crops and range lands, relatively inaccessible forrested areas, greenbelts and landscaped open spaces associated with highways, airports, parks, and golf courses, and for reclamation of sterile soils, borrow pits, and similar areas.

The kinds of sites potentially suitable for land application of residual solids, therefore, consist prinicipally of: (1) agricultural lands, (2) relatively inaccessible forested areas, (3) greenbelts, (4) landscaped open spaces of highways, airports, parks and golf courses, (5) borrow pits and strip mines and (6) sanitary landfill sites.

The treatment required for various wastewater sludges and solids that are separated from the main wastewater stream is determined by two basic considerations. The first consists of the treatment required to facilitate the integration of the residual solids into the soils in a manner that is harmonious with the functioning of the soil and vegetative subsystems of the site and adjacent lands and water bodies. The second is that treatment required to facilitate the transportation, storage and distribution of the residual solids. Specific pretreatment processing will be discussed in the following sections as they are associated with the major methods of land disposal. The quantities of the most significant wastewater sludges and residual solids separated from the main wastewater process stream, projected for the year 2000, are summarized in Table III-G-1. Table III-G-2 which follows, summarizes land disposal and application of all the wastewater residual sludges and solids (municipal and industrial) produced in the 12-county waste source region, in the year 2000, in the following terms: (1) by the kind and condition of each solid, (2) by the estimated effective volume and total dry solid masses produced per day for each kind and condition and, therefore, the relative amounts available for some manner of disposal or useful application, (3) by the estimated effective bulk densities and percent moisture content for each kind and condition, (4) by the amount of acres per year specifically required for each in order to bury the material assuming 6 feet of actual burial depth or thickness (common in current sanitary landfill practise) and (5) by the

amount of acres per year required for land applications for some of the sludges based on several representative surface spreading rates, the latter in terms of dry tons per acre per year. Figure III-G-5, at the end of this chapter, presents an illustrated summary of land disposal of wastewater sludges and residual solids.

Table III-G-1

ESTIMATED QUANTITIES OF FRESHLY SEPARATED WASTEWATER SLUDGES AND SOLIDS
COMBINED MUNICIPAL AND INDUSTRIAL
12-COUNTY WASTE SOURCE REGIONAL TOTALS – YEAR 2000

County	Projected Wastewater Flows in MGD	SCREENINGS		GRIT		SKIMMINGS		MIXED ORGANIC SLUDGES		LIME SLUDGES	
		cf/d (gpd)	Tons/d dry solids	cf/d (gpd)	Tons/d dry solids	cf/d (gpd)	Tons/d dry weight	cf/d (MGD)	Tons/d dry solids	MGD	Tons/d dry solids
San Francisco	130	130 (973)	0.78	1300 (9730)	59	1290 (9650)	15	108,000 (0.81)	135	1.61	336
San Mateo	98	98 (733)	0.59	980 (7330)	44	916 (6850)	11	114,000 (0.85)	142	1.21	252
Santa Clara	350	350 (2620)	2.10	3500 (26,200)	158	3390 (25,400)	41	289,000 (2.16)	360	4.28	896
Alameda	208	208 (1560)	1.25	2080 (15,600)	94	1650 (12,350)	20	183,000 (1.37)	228	3.09	645
Contra Costa	347	347 (2590)	2.08	3470 (25,900)	156	4270 (31,600)	51	243,000 (1.82)	303	5.60	1150
Marin	60	60 (450)	0.36	600 (4500)	27	460 (3440)	5	40,000 (0.30)	50	0.67	140
Sonoma	45	45 (337)	0.27	450 (3370)	20	368 (2750)	4	28,900 (0.22)	36	0.31	64
Napa	21	21 (157)	0.13	210 (1570)	10	275 (2060)	3	14,400 (0.11)	18	0.27	56
Solano	71	71 (532)	0.43	710 (5320)	32	1010 (7550)	12	40,000 (0.30)	50	0.67	140

Alameda	208	208 (1560)	1.25	2060 (15,600)	94	1650 (12,350)	20	183,000 (1.37)	228	3.09	645
Contra Costa	347	347 (2590)	2.08	3470 (25,900)	156	4270 (31,600)	51	243,000 (1.82)	303	5.60	1150
Marin	60	60 (459)	0.36	600 (4500)	27	460 (3440)	5	40,000 (0.30)	50	0.67	140
Sonoma	45	45 (337)	0.27	450 (3370)	20	368 (2750)	4	28,900 (0.22)	36	0.31	64
Napa	21	21 (157)	0.13	210 (1570)	10	275 (2060)	3	14,400 (0.11)	18	0.27	56
Solano	71	71 (532)	0.43	710 (5320)	32	1010 (7550)	12	40,000 (0.30)	50	0.67	140
Yolo	40	40 (300)	0.24	400 (3000)	18	368 (2750)	4	26,500 (0.20)	33	0.31	64
Sacramento	161	161 (1200)	0.97	1610 (12,000)	73	1190 (8900)	14	105,000 (0.79)	131	1.61	336
San Joaquin	77	77 (580)	0.46	770 (5800)	35	368 (2750)	4	66,500 (0.50)	83	0.31	64
Totals	1608 (1,800,000) (acre-ft/yr)	1608 (12,000)	9.66	16,080 (120,000)	726	15,555 (116,050)	184	1,258,300 (9.43)	1569	19.94	4143
Avg. Regional Unit Values		12 lbs/MG		905 lbs/MG		229 lbs/MG		1955 lbs/MG		5160 lbs/MG	
Specific Unit Values for Calculations		12 lbs/MG 20% TS, 60 pcf		900 lbs/MG 50% TS, 180 pcf		1/ 40% TS, 59 pcf		2/ 4% TS, 62 pcf		3/ 5% TS, 62 pcf	

NOTE: TS = Total Solids pcf = pounds per cubic feet cf/d = cubic feet per day gpd = gallons per day
MGD = million gallons per day
1/ Skimmings lbs/MG = 0.77x8.34 lbs/MG/mg/l x mg/l (Influent O&G) See Table II-B-9
2/ Mixed Organic Sludges /MG = 0.90x8.34 lbs/MG/mg/L x mg/l (Influent Total Suspended Solids) See Table II-B-9
3/ Lime Sludges lbs/MG = 41.25x8.34 lbs/MG/mg/l x mg/l (Secondary Effluent Total Phosphorous) See Table II-B-10

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Table III-G-2

SUMMARY OF LAND DISPOSAL AND APPLICATIONS OF RESIDUAL WASTEWATER SLUDGES AND SOLIDS
For 12-County Waste Source Region in Year 2000 - Combined Municipal and Industrial

Solids Type	Regional Quantities Produced				Acres/Year Land Area Required					
	1000 cf/day	T/D dry solids	Assumed Density lbs/cf	% Water	Burial @ 6' Depth	Land Spreading Rates Tons/dry solids/acre/year 5	20	30	50	100
SCREENINGS										
Fresh	1.6	9.66	60	80	---					
Washed	1.34	8	60	80	1.86					
Dewatered	0.8	8	57	65	1.1					
Incinerated	0 32	7.7	48	-0-	0.45					
GRIT, washed	16.0	726	180	50	22.4					
SKIMMINGS										
Fresh	15.6	184	59	60	21.8					
Dewatered	10.6	184	58	40	14.8					
Incinerated	2.5	37	30	-0-	3.4					
ORGANIC SLUDGES										
Fresh	1,260.0	1569	62	96	1800	---	---	---	---	---
Mechanically Dewatered	840.0	1569	62	94	1173	---	---	---	---	---
Wet Digested	514.0	800	62	95	720	58,400	14,600	9733	5840	2920
Thickened Wet Digested	257.0	800	62	90	360	58,400	14,600	9733	5840	2920
Air Dried Digested - uncompacted	147.0	800	22	50	---	58,400	14,600	9733	5840	2920
Air Dried Digested - compacted	53.4	800	60	50	75	---	---	---	---	---
Ash, compacted	18.0	628	70	-0-	16	---	---	---	---	---
Aerobically Composted	71.5	1270	48	26	---	---	---	---	---	---
LIME SLUDGES										
Fresh	2,660.0	4143	62	95	---					
Lime (CaO) content		1400-2000								
P-sludge-$Ca_5(OH)(PO_4)3$		± 667								
Removed Suspended Solids		± 122								

SCREENINGS										
Fresh	1.6	9.66	60	80	---					
Washed	1.34	8	60	80	1.86					
Dewatered	0.8	8	57	65	1.1					
Incinerated	0.32	7.7	48	-0-	0.45					
GRIT, washed	16.0	726	180	50	22.4					
SKIMMINGS										
Fresh	15.6	184	59	60	21.8					
Dewatered	10.6	184	58	40	14.8					
Incinerated	2.5	37	30	-0-	3.4					
ORGANIC SLUDGES										
Fresh	1,260.0	1569	62	96	1800	---	---	---	---	---
Mechanically Dewatered	840.0	1569	62	94	1173	---	---	---	---	---
Wet Digested	514.0	800	62	95	720	58,400	14,600	9733	5840	2920
Thickened Wet Digested	257.0	800	62	90	360	58,400	14,600	9733	5840	2920
Air Dried Digested - uncompacted	147.0	800	22	50	---	58,400	14,600	9733	5840	2920
Air Dried Digested - compacted	53.4	800	60	50	75	---	---	---	---	---
Ash, compacted	18.0	628	70	-0-	16	---	---	---	---	---
Aerobically Composted	71.5	1270	48	26	---	---	---	---	---	---
LIME SLUDGES										
Fresh	2,660.0	4143	62	95	---					
Lime (CaO) content		1400-2000								
P-sludge-$Ca_5(OH)(PO_4)_3$		± 667								
Removed Suspended Solids		± 122								
Removed BOD		± 216								
Removed organics		max.1440								
Removed Diss. Solids		1850-2680								
Thickened	1,325.0	4143	62	90	1890					
Recalcined Residue	153.0	max.2300	30	-0-	---					
Recalcined Residue - compacted	66.0	max.2300	70	-0-	92					

NOTES:

T/D = Tons per Day

P.B.Q & D, Inc.

2

2 - Criteria for Land Application of Residual Wastewater Solids

a. General Criteria

The overall criteria for land applications of wastewater sludges and other residual solids emphasize compatibility with existing and future land uses, compatibility with the recognized and projected beneficial uses of water, air, soil, biotic, and scenic resources associated with these land uses, and the protection or enhancement of the quality of various elements in the environment. The quality conditions should be substantially reflected in the current air and water quality standards which have force and effect in the study region (Refs. 182, 183, 184, 187; sub-appendix section III-D-8).

The primary study region constitutes one of the major metropolitan regions in the country. Increased pressure is being applied to its water, air, and land resources, resulting in a demand for greater multiple use of these resources. This means that the more environmental quality demanding uses will generally determine the level of quality management. The most demanding beneficial uses are those of fish, game and wildlife conservation, public water supplies and recreation with public health requirements, and aesthetic or scenic enjoyment.

The land application of residual solids involves several essential approaches, these having been outlined in the previous section. It would appear socially advantageous to maximize the reuse or recycling of residual solids in order to reduce the amounts to be disposed of, thereby minimizing the requirement for land areas that would have to be devoted to that purpose.

b. Solids Wastes Disposal Sites and Associated Criteria

The disposal of residual wastewater solids and sludges in public refuse disposal and sanitary landfill sites is one distinct alternative in the management of these waste solids. The State of California has classified refuse disposal sites into three categories according to their water pollution control potentials (Refs. 192, 193; also sub-appendix section III-G-11). Summaries of these classifications follow.

1. Class III sites are limited to disposal of non-water soluble, non-decomposable, inert solids. This includes construction and demolition wastes and some industrial wastes, e.g., rocks, masonry, glass and some metals. These materials are considered non-polluting and, therefore, can be placed anywhere without impairing the quality

of nearby water bodies. Earth cover and landscaping treatment may be required because of location-related aesthetic and scenic considerations.

2. Class II sites are limited to Class III materials together with decomposable organic wastes. This includes household garbage, crop residues and vegetative debris, paper, wood products, animal wastes and decomposable demolition and construction wastes. Class II sites must be 10 to 15 feet above the water table and must be sited so that no surface water can drain into any adjacent body of water. Class II sites constitute typical sanitary landfills.

3. Class I sites are limited to Class III and Class II materials and toxic chemicals, soluble industrial wastes, saline brines and unquenched incinerator ashes. Class I sites must be situated on non-permeable soil above a water table which is not currently being used as a source of water supply. Such sites cannot be near streams or other surface water bodies.

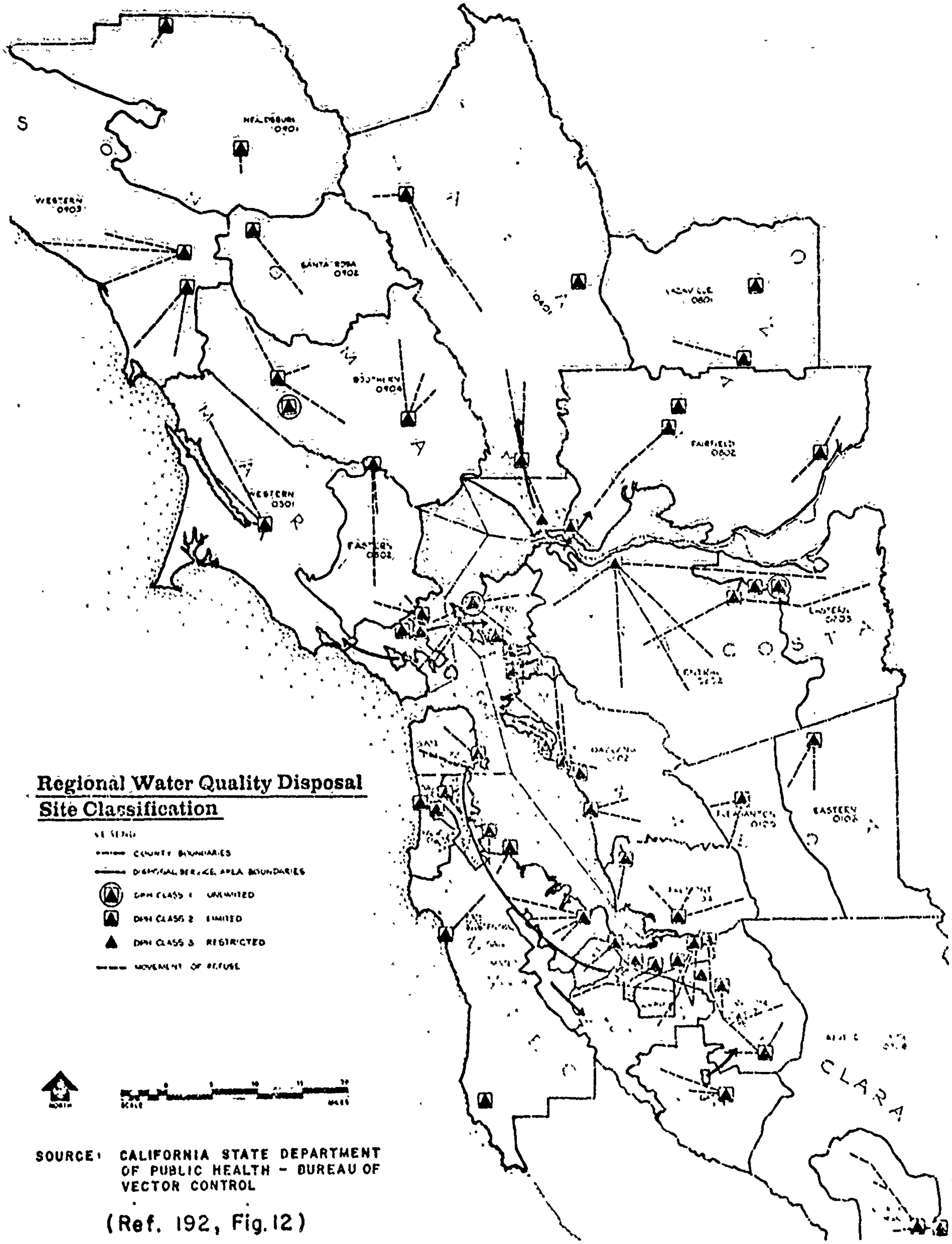
The location, classification and capacity for 1971 refuse disposal sites in 9 of the 12 counties of the Bay region as defined in this study are shown in Figures III-G-1 and III-G-2.

c. Some Specific Criteria

In reviewing the preceding generalized criteria, the previously outlined objectives in relation to the specific types of residual waste-water solids and the criteria associated with public solids wastes disposal sites, some following specific criteria or requirements for land application of residual solids become fairly self-evident.

Separate independent burial or sanitary landfilling operations for residual wastewater solids should be located and managed much the same as public refuse disposal sites depending, of course, on the nature of the waste material involved.

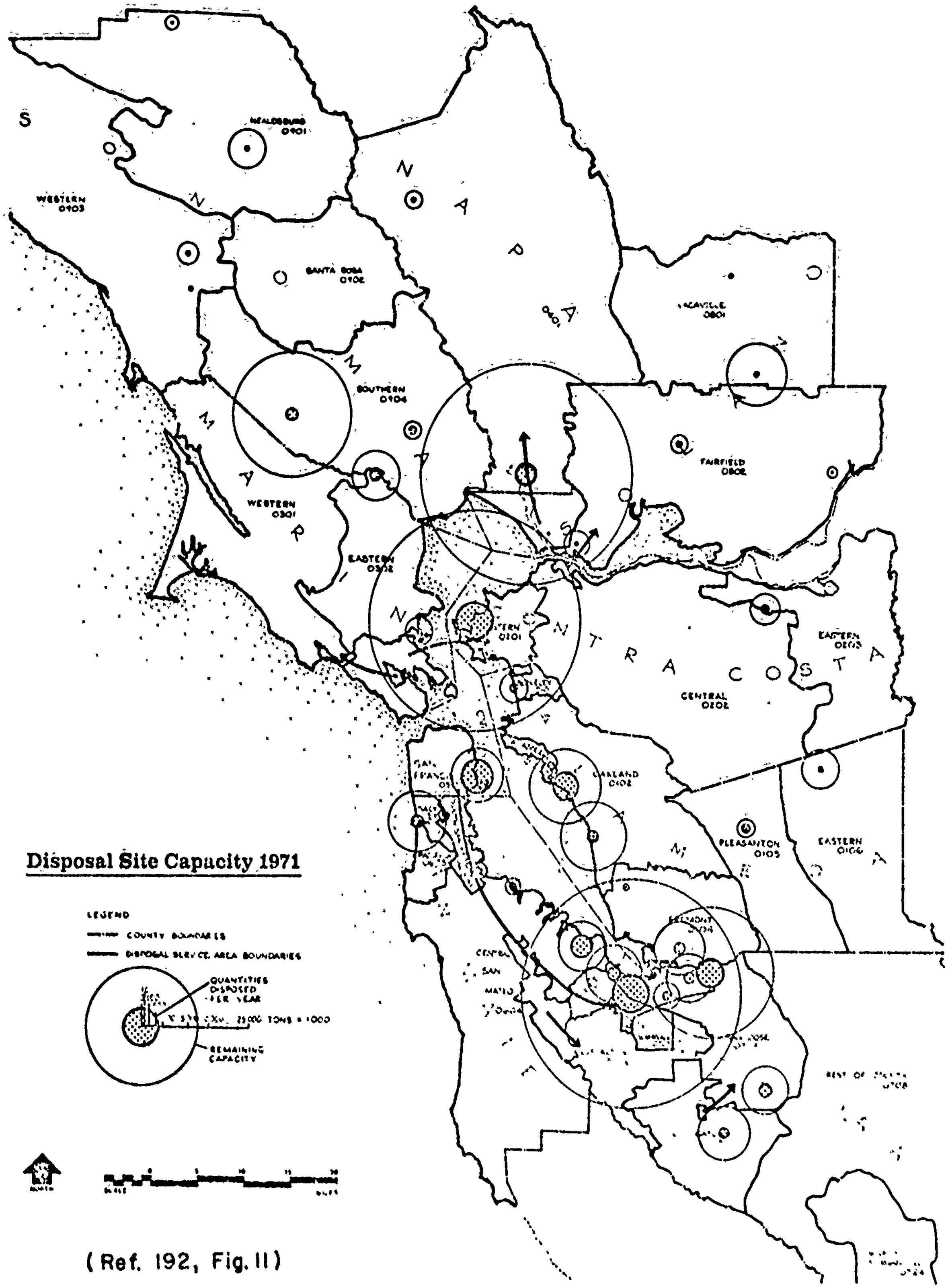
Toxic solids, which are isolatable, must be buried. The likelihood of their economic recovery and reuse or effective neutralization appears remote. The burial sites must be selected so that the lower depth of the buried material is safely above the water table. The manner of burial must involve encapsulation and covering with impervious materials in order to minimize the amount of leaching out of toxic substances and to severely reduce the rate of out-migration. Toxic solids should be reasonably dry before burial. Such burial sites should not be located in flood plains where real possibilities of a flood washout are present. Toxic solids are the only type of residual wastewater solid



SOURCE: CALIFORNIA STATE DEPARTMENT OF PUBLIC HEALTH - BUREAU OF VECTOR CONTROL

(Ref. 192, Fig. 12)

Figure III-G-1



(Ref. 192, Fig. II)

Figure III - G-2

that must be buried, with the exception of the inorganic bulky refuse-like component of bar-rack screenings.

Non-toxic landfill disposal should generally be avoided in flood plains and should generally be situated above the groundwater table. Any sites located in flood plains will require impervious bottoms and sides, together with dikes or embankments designed to protect against 100-year floods.

Wherever possible, land applications should involve some measure of beneficial use of enhancement of the environment. Examples of this include irrigation of crop and pasture lands, range lands, green belts, etc. The manner and rate of irrigation and spreading, the degree of pretreatment and the relative isolation of the site are intimately related. Consideration must be given to suppressing nuisance conditions (flies, odors, etc.), the drainability of the soil, propensities for clogging, magnitude and distribution of annual rainfall, susceptibility to flooding, "treatment" and ion exchange capacity of the soil, subsoil and the crop or vegetative cover, depth to groundwater, distance from the nearest surface waters, and evaporation and evapotranspiration rates. The water quality objectives designated for groundwaters and surface waters will be the governing factors. The basic objective is clear: the facilitation of the absorption of the residual solids into the habitat in such a manner as not to deleteriously affect the functioning or condition of the soil and vegetative subsystems and the beneficial use of the site, adjacent lands and water bodies. The environmental impact assessment involves a water and solid constituents mass balance approach.

Most of the wastewater land disposal criteria developed in Appendix Chapters II-D and II-3 apply to the land application of wastewater sludges and residual solids. There are a significant number of variations to produce an array of potential or candidate sites for the various methods of land disposal.

3 - Land Disposal of Screenings

It is estimated that, in the project year 2000, approximately 1600 cubic feet per day (or 12,000 gallons per day) of raw wet screenings will be produced in the 12-county waste source region, this containing 9.66 tons per day of dry total solids (from Table III-G-1). About two tons per day dry solids are organic. The remaining eight tons per day of dry screenings solids represent the bulky, inorganic, refuse-like component of these screenings. These values are based on an assumed

typical loading rate of one cubic foot of wet screenings solids per million gallons (MG) of influent (see Table III-G-2), a typical reported bulk density of 60 pounds per cubic foot at 80 percent moisture content (Ref. 9), and therefore of an equally typical dry total solids loading rate of 12 pounds per MG, the assumed projected wastewater flows listed in Table III-G-1, together with the assumption that the organics constitute 20 percent of the total dry solids.

The screenings solids, particularly the organics, can be physically reduced in size by various means and returned directly to the wastewater process stream where they can be subsequently removed with the organic or lime sludges in sedimentation tanks or be mixed directly with the already removed sludges in the digesters.

a. Burial or Sanitary Landfilling

Pretreatment. Subsurface disposal by burial or sanitary landfilling is specifically suited to the inorganic refuse-like component of bar-rack screenings. The pretreatment required or deemed advisable consists of:

1) Physical size reduction.

2) Washing the organic component out and back into the wastewater process stream or its separation from the inorganic component in a hammermill-grinder

3) Possibly dewatering to about 65 percent moisture in presses or centrifuges (Refs. 6, 24, 154), a process which approximately reduces by one-half the original raw screenings volume.

4) An alternate method of dewatering would be the use of a draining platform (Refs. 9, 154) draining for about one day, with lime being used to control any offensive odors due to the insufficient removal of putrescible organics and their subsequent anaerobic decomposition.

The unwashed screenings can be disposed of in Class II sanitary landfill disposal sites. Thoroughly washed screenings with practically all of the organic portion removed can be disposed of in Class III refuse disposal sites. If the screenings are kept separate from the other residual solids and sludges (see Section III-B-3), pretreatment could

consist of dewatering with disposal in a Class II sanitary landfill, incineration with disposal of the ash in a Class III disposal site or on-treatment plant site equivalents (Refs. 9, 24, 154). High temperature volume reduction by incineration can encompass special screenings incinerators, combined skimmings-scum-screenings incinerators, completely mixed sludge incinerators, or combined sludge-refuse incinerators (Refs. 9, 154). Careful design for odor control is important with separate screenings incinerators.

Burial Rates and Specific Site Criteria. Independent burial of coarse and medium screenings usually involves placement in holes or trenches and immediate covering with at least six inches of dirt (Refs. 9, 154). Again, lime and odor-masking chemicals can be employed to control odors, insect breeding and other nuisances. Such burial is preferably confined to the treatment plant site where isolation and size will permit it. The location and management of the burial operations are essentially the same as those for any good sanitary landfill (Ref. 16, 17, 19, 23, 180, 181, 188-191). Of particular importance is the proper management of drainage and percolation. If burial is inappropriate at the treatment site, the nearest available public sanitary landfill might be used unless closer sites are available. The contamination potential from various residual wastewater solids and sludges can be greatly mitigated by a properly located, designed and operated sanitary landfill (Ref. 186). The final top grade should be sloped to allow surface water drainage and be planted with a grass cover. The mixing of organic sludges with dry refuse and particularly with dewatered or dried sludge helps prevent subsequent saturation and leaching.

Estimated annual land requirements for such independent burial or sanitary landfilling, for the project year 2000, for coarse and medium screenings from the entire 12-county waste source region are presented in Table III-G-3 together with several assumed and calculated values. The land requirement is based on the assumption of a burial thickness or depth of six feet. Six feet is the average depth of thickness of deposition of compacted refuse materials in current American sanitary landfilling practice. As indicated, volume reduction by incineration will produce a residue occupying 10 to 20 percent of the original raw screenings volume.

Table III-G-3
SCREENINGS: BURIAL REQUIREMENTS AND
OTHER UNIT VALUES **

	Types of Screenings			
	Fresh	Washed	Dewatered	Incinerated
Burial Requirement*				
Acres/year (regional total)	--	1.86	1.1	0.45
Acres/year/MGD	--	0.00116	0.00068	0.00028
Acres/year/ton dry fresh screenings solids per day		0.193	0.114	0.0466
Acres/year per cf/MG		1.86	1.1	0.45
Acres/year per lbs. TdS/MG (fresh)		0.155	0.092	0.0375
Other Unit Values				
Volume: cf/day (regional total)	1608	1335	800	320
Unit volume: cf/MG	1.0	0.83	0.5	0.2
Total dry solids: tons/day	9.66	8	8	7.7
Unit TS: lbs/MG	12	9.6	9.6	9.5
Assumed moisture content	80%	80%	65%	0%
Assumed bulk density: lbs/cf	60	60	57	48
Assumed total volatile solids: % of total dry solids	20%	4%	4%	0%

* Assumed burial depth or thickness of 6 feet

** For 12-county waste source region, year 2000, combined municipal and industrial wastewaters

b. Miscellaneous Disposal Methods

None of the other outlined methods for the land disposal of residual wastewater sludges and other solids is applicable to screenings. The organic portion of screenings can, after suitable physical size reduction, be composted or digested when mixed with the predominant organic sludges (Ref. 24).

4 - Land Disposal of Grit

It is estimated that, in the project year 2000, approximately 16,000 cubic feet per day (or 120,000 gallons per day) of fresh grit will be produced in the 12-county waste source region, this containing 726 tons per day of total dry grit solids per day (Table III-G-1). These values are based on an assumed typical loading rate of 10 cubic feet of washed grit per MG of influent (see Table III-B-2), an assumed effective bulk density of 180 pounds per cubic foot, and therefore an equally typical dry total solids loading rate of 900 pounds per MG, the assumed projected wastewater flows listed in Table III-G-1, together with the assumption of 50 percent moisture content.

a. Burial or Sanitary Landfill

Pretreatment and Specific Site Criteria. Grit with a high concentration of organic materials (detritus) would in all probability have to be buried or placed in sanitary landfills (Refs. 24, 154). The independent burial of such grit and detritus, either on the treatment plant site, at suitable short-haul distances from the site, or in sanitary landfills would be handled the same as that for screenings discussed in the previous section. Such burial or sanitary landfilling could be combined with that for screenings. No particular pretreatment is required other than the possible use of lime and some odor-masking chemicals. Sanitary landfilling may also be involved when the grit is mixed in with the larger mass of organic sludges. The pretreatment requirements for the latter are determined by the needs for volume reduction of the organic sludges and this is discussed in a following section.

Burial Rates. It is estimated that the annual land requirements for the independent burial or sanitary landfilling of washed grit from the entire 12-county waste source region, at projected year 2000 levels, for approximately 16,000 cubic feet per day of volume will be about 22.4 acres, assuming six feet of burial depth or thickness. In unit terms, the burial requirement is 0.0139 acre-feet per year/MGD, or 0.0309 acre-feet/year per ton/day dry grit solids, or 2.24 acre-feet/year per cf/MG of washed grit, or 0.0249 acre-feet/year per lb/MG of washed grit.

b. Landfilling and Dry Surface Spreading

These methods of disposal of grit are suited to grit whose organic component has been reduced at least to 10-15 percent of the dry solids. Pretreatment can include the following:

1) More efficient solids separation in the grit tank, with less than 15 percent volatile solids content, allowing disposal as a fill without nuisance (Ref. 154).

2) Use of a grit washer to wash out the lighter detritus organics which are returned to the wastewater process stream (Refs. 6, 24, 154).

3) The use of grit tank scrapers and removal conveyors and supporting mechanisms which wash out the organic particles in grit as it is moved through and out of the wastewater (Refs. 6, 24, 9).

4) Use of compressed air in order to lift out the lighter particles (Refs. 6, 24).

5) Incineration with sludge or refuse or both with the subsequent disposal of the inorganic grit residue along with the ash (Ref. 154).

6) Composting along with sludge, perhaps by itself (see sections III-B-2 and III-F).

Well washed grit can be used on sludge drying beds as a cover for screenings and as a construction material for walks, roads and parking areas (Ref. 154). Incinerated grit can be disposed of in a Class III disposal site. Composted grit can be landfilled in a number of ways.

5 - Land Disposal of Skimmed Oil and Grease

It is estimated that, in the project year 2000, approximately 15,600 cubic feet per day (or 116,200 gallons per day) of fresh skimmings and scum will be produced in the 12-county waste source region. This volume will contain about 184 tons per day of skimmings and scum on a dry weight basis (from Table III-G-1). About 169 tons per day dry solids will be skimmed oil and grease. The remaining 15 tons per day dry solids are other materials such as floating fibrous trash which are removed with the oil and grease when scums are skimmed and removed from the wastewater process stream. About 10 percent has been added to the skimmed oil and grease values to allow for this other material.

These values are based on the following assumptions:

1) That 70 percent of the oil and grease is removed in the secondary treatment process, and that they have been isolated from the other residual wastewater solids components.

2) A typical bulk density of 59 pounds per cubic foot and a moisture content of 60 percent.

3) The assumed projected wastewater flows listed in Table III-G-1 and II-B-9.

4) The assumed projected influent oil and grease concentrations listed in Table II-B-9.

5) The use of the following formula: total dry skimmings solids in lbs/MG = 0.77 x 8.34 lbs/MG/mg/1 x mg/1 influent O&G (Table II-B-9).

The average regional loading rate for fresh skimmings was estimated to be 229 pounds of total dry skimmings solids per million gallons with a volume loading rate of about 9.7 cubic feet per MG of influent wastewater.

a. Burial or Sanitary Landfill

Burial is the major method of disposal of skimmings or the dry residue of skimmings (Refs. 6, 9, 24, 31, 36, 154). This is particularly true when significant amounts of mineral oils (petroleum oils and solvents, synthetic oils) are present to inhibit the easy digestion of the scums. The independent burial of skimmings, either on the treatment plant site, at a suitable short-haul distance from the site or in sanitary landfills, would be handled in the same way as that discussed for screenings. Skimmings could be combined with screenings and grit for burial or sanitary landfilling. Sanitary landfilling may also be involved when the skimmings are pumped to sludge digestion units and mixed with the great mass of organic sludges. Such diversion to the digestion units is considered particularly applicable with completely mixed digester units and the absence of troublesome quantities of mineral oils in the skimmings. Without thorough mixing, operational problems with the digester units can result due to the formation of a scum layer from these skimmings.

Pretreatment and Burial Rates. Minimal pretreatment is associated with quick burial, immediate covering and the use of lime and other odor-masking chemicals. With skimmings having higher ranges of water content, dewatering by decantation can be employed with subsequent burial or quick disposal of the floating oils and greases.

More thorough dewatering may be advisable and this would require the use of mechanical dewatering methods. Such mechanical dewatering requires careful controls to avoid plugging of filtering or straining media (Ref. 154). The use of vacuum filters would usually require prior mixing with other more easily drainable materials but could be employed subsequent to the formation of an organic sludge pre-coat.

Incineration of skimmings represents a maximum form of pretreatment prior to burial of the residual ash. Its viability as a pretreatment alternate is associated with increasing skimmings quantities, significant mineral oil components in the skimmings, limitations on acreage for burial or sanitary landfilling, greater haul distances to disposal sites and problems in pumping skimmings. The pumping consideration favors separate skimmings incineration at the source of the skimmings (at the skimming tank or sedimentation tank) or combination incineration with screenings where the latter can easily be transported to the special incinerator involved. A common combination (Ref. 154) is the incineration of skimmings with vacuum filter or centrifuge organic cake solids. The incineration of skimmings requires other pretreatment unit operations such as settling and decanting of the liquid portion and grinding of the skimmings solids to a small size.

Estimated annual land requirements for the independent burial or sanitary landfilling of fresh, dewatered and incinerated skimmings from the entire 12-county waste source region, for the project year 2000, are presented in Table III-G-4 together with several assumed and calculated values.

Table III-G-4
SKIMMINGS: BURIAL REQUIREMENTS AND
OTHER UNIT VALUES **

	Types of Skimmings		
	Fresh	Dewatered	Incinerated
Burial Requirement*			
Acres/year (regional total)	21.8	14.8	3.43
Acres/year/MGD (regional average)	0.01135	0.0093	0.00213
Acres/year/tons/day dry fresh skimmings solids (regional average)	0.119	0.081	0.0186
Acres/year per mg/l influent O&G removed	0.865	0.588	0.136
Other Unit Values			
Volume: cf/day (regional total)	15,600	10,600	2,450
Volume: gpd (regional total)	116,200	79,500	18,300
Unit volume: cf/MG (regional average)	9.7	6.5	1.5
Total dry solids: tons/day (regional total)	184	184	36.8
TdS: lbs/MG (regional average)	229	229	45.8
Assumed moisture content	60%	40%	0%
Assumed bulk density: lbs/cf	59	58	30
Assumed total volatile solids, as % of TdS	80%	80%	0%

* Assumed burial depth or thickness of 6 feet

** Assumes all oil and grease removed by secondary treatment have been isolated from other sludge and residual solids components. Also to 12-county waste source region, year 2000, combined municipal and industrial wastewaters.

6 - Land Disposal of Organic Sludges

Organic sludges are the major fraction of combined municipal and industrial wastewater solids to be removed from the wastewater process stream. It is estimated that, in the project year 2000, approximately 1.3 million cubic feet per day (9.43 MGD) of freshly settled and combined primary and secondary settled sludges will be produced in the 12-county waste source region assuming secondary levels of treatment based on the activated sludge process (from Table III-G-1). This volume will contain about 1600 tons per day of organic solids (on a dry weight basis) assuming 4 percent total solids concentration.

These values are based on the following assumptions:

1) That 90 percent of the total suspended solids (TSS) is removed in the secondary treatment process.

2) A bulk density of 62.4 pounds per cubic foot at a moisture content of 96 percent.

3) The assumed projected wastewater flows in Table III-G-1 and II-B-9.

4) The assumed projected influent TSS concentrations listed in Table II-B-9.

5) The use of the following formula: total mixed organic sludges in lbs/MG = 0.90 x 8.34 lbs/MG/mg/L x mg/l influent TSS (Table II-B-9).

The average regional loading rate for freshly separated mixed organic sludges was estimated to be 1995 pounds of total dry sludge solids per million gallons of influent with volume loading rate being about 783 cubic feet/MG (about 0.59 percent of the influent wastewater flow rate).

a. Burial or Sanitary Landfilling

Burial is one alternate method of disposal of mixed organic sludges (Refs. 6, 9, 24, 31, 154, 186 and 192). Such sludges can be buried in any state: raw, digested or incinerated; wet, partially dewatered or dry; or in any combination of these states. Disposal site availability, suitability and economics will determine optimal characteristics. Consequently, various quantities and volumes are

potentially involved and each is associated with certain sequences of pretreatment operations.

Specific Site Criteria. Disposal of wet sludges by trenching and earth cover usually has limited applicability. At smaller treatment plants with sufficient available site acreage, this burial can involve digging shallow trenches and filling them with raw or digested sludges. This is not likely at larger treatment works and, therefore, transport to a sanitary landfill or a separate site would be required. Sanitary landfilling would require at least partially dewatered organic sludges and preferably dried sludge cake. For smaller and more isolated plants, digested sludges can be pumped onto nearby land areas and plowed under.

Landfill disposal of the various sludges or sludge residues will require Class II sites. Current Bay Area Class II sites are shown in Figures III-G-1 and III-G-2.

It has been predicted that these sites will be filled up by about 1995 (Ref. 192). This indicates the necessity for maximum reduction of sludge volumes if burial or sanitary landfilling are to be considered viable alternatives.

The criteria for separate burial or sanitary landfill sites for handling sludges by themselves should be governed by those criteria already developed for public refuse disposal sites.

Pretreatment and Burial Rates. Three basic pre-disposal treatment operations are employable: gravity thickening and/or mechanical dewatering, digestion, and incineration (Ref. 154). Incineration currently employs the thickening, conditioning, and dewatering of raw sludges; digestion being avoided. Raw wet sludges would require no pre-disposal treatment.

With digestion, a 50 percent reduction in the total initial total dry solids can be expected. Digestion reportedly "destroys" an average of 67 percent of the volatile content of the raw sludge (Ref. 154) with the observed range being reported between 55 and 75 percent (Ref. 9). The City of San Diego (Ref. 196) reportedly disposed of 0.12 MGD of wet digested sludge (at 10 percent total dry solids, 50 tons per day dry solids) in 1968 by pumping it to a sanitary landfill at a cost of $7.30 per dry ton. This cost includes the amortization of mechanical and electrical equipment at 5 percent over a twenty-year period. It does not include the cost of land. No breakdown between amortization and operation and maintenance was given. Estimated sanitary landfill

burial costs, based on 1961-65 refuse disposal sanitary land costs (Refs. 23, 154), range between $1.00 to $4.00/ton for operation and approximately $2.00/ton for capital costs.

Estimated annual land requirements for the independent burial or sanitary landfilling of various mixed organic sludges from the entire 12-county waste source region, for the project year 2000, are presented in Table III-G-5 together with several assumed and calculated unit values.

b. Deep-well Injection

The subsurface disposal of organic sludges by deep-well injection can be considered as one alternate method of disposal (Ref. 154). Almost all of the current uses of deep-well disposal, however, involve wastewaters (Refs. 154, 203-206). A review of the literature reveals only one clear example of sludge disposal by this method (Ref. 154) and that involves a waste activated sludge from one of the large production facilities of the Dow Chemical Company. The other near-sludge example involves radioactive wastes. This will be discussed further in section III-G-8.

Burd (Ref. 154), in his 1968 review of sludge handling and disposal, briefly explored deep-well injection disposal possibilities. The value of this approach is due to its apparent potentialities for greater economics when compared to current conventional handling and disposal methods. Economic analysis has indicated potential cost savings up to half of that associated with current conventional methods. The method depends on suitable subsurface geology and the ability of the receiving strata to accept the high concentrations of suspended materials found in organic sludges. Deep-well injection costs are influenced by the following factors:

1) Volume of sludge to be wastes.

2) Well depth.

3) Well head pressure affected by the physical and chemical characteristics of the subsurface formation.

4) Sludge concentration.

5) Required surface treatment, depending on the nature of the subsurface formation and the nature of the sludge.

Table III-G-5
MIXED ORGANIC SLUDGES:
BURIAL REQUIREMENTS AND OTHER UNIT VALUES**

	Types of Sludges				
	Wet Raw	Thickened Raw	Wet Digested	Thickened Digested	Incinerated
Burial Requirements*					
Acres/yr (regional total)	1800	1173	720	75	26
Acres/yr/MGD (regional average)	1.12	0.73	0.448	0.0466	0.0162
Acres/yr/ton raw Tds/day (regional average)	1.15	0.748	0.459	0.0478	0.0166
Acres/yr per mg/l influent TSS removed	7.60	4.95	3.04	0.316	0.1095
Acres/yr per ton/day of raw TIS	--	--	--	--	0.55****
Other Unit Values					
Volume: 1000 CF/day (regional total)	1,258.3	840	514	53.4	0.018
Volume: MGD	9.43	6.27	3.84	0.4	--
Unit Vol: cf/MG (regional average)	783	522	319	33.2	11.2
Total dry solids: tons/day (regional total)	1569	1569	800	800	628
TdS: lbs/MG (regional average)	1995	1995	995	995	780
Assumed moisture content	96%	94%	95%	50%	0%
Assumed bulk density lbs/cf	62.4	62.4	62.4	60***	70***
Assumed total volatile solids, as % of TdS	70%	70%	41%	41%	0%****

* Assumed burial depth of thickness of 6 feet

** For 12-county waste source region, year 2000, combined municipal and industrial wastewaters

Total Inert Solids = TIS = TdS + TVS

*** Compacted (Ref. 128)

**** Conditioning chemicals added to facilitate raw sludge dewatering more than make up for TVS incinerated. 1.33 lbs of ash produced per lb. of raw TVS. Its volume is 16.4 cf/ton raw TVS

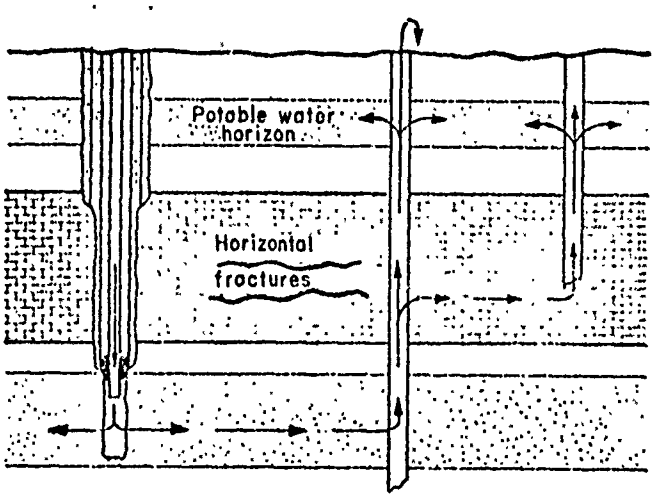
Burd has also pointed out that mineral production in the U.S. creates about 152 million gallons per day of underground cavity capacity, 116 MGD of which are in bituminous coal cavities. This is not particularly applicable, however, to this study area.

Tofflemire and Brezner (Ref. 206), in their 1970 review of deep-well injection of wastewater, paid little attention to waste sludge possibilities. They concluded that deep-well injection should be reserved only for certain hard-to-treat types of wastewaters and considered only in areas geologically suitable. They indicated that the most suitable strata are sand, sandstone and limestone. They further indicated that the waste should be high in concentration, low in volume, noncorrosive and free of suspended solids and micro-organisms. This would exclude organic sludges, unless ample total storage is available.

Indications are that the subsurface geology of most of the Bay Area and the Central Valley should be generally well suited to deep-well injection. Douglas D. McLean of the Canadian Department of Mines and Northern Affairs (Ref. 203) has recommended that deeper Cambrian formations may be preferable for deep-well waste injection from the viewpoint of minimizing or avoiding possible contamination of groundwater aquifers. Figure III-G-3 illustrates this point.

Figure III-G-3

CONTAMINATION FROM DEEP-WELL INJECTION OF WASTES



Province of Ontario, Canada, encountered trouble with deep-well disposal because unplugged or inadequately plugged wells (center and right) extended into the stratum into which the disposed wastes were injected.

CONTAMINATION FROM DEEP-WELL INJECTION OF WASTES

Figure III-G-3

(Ref. 203)

From the foregoing, it is evident that specific site information will be needed to fully evaluate the possibilities of this method of disposal for organic sludges. In addition, the deposition of reasonably concentrated sludges into formations similar to those in which oil or natural gas are found should be explored, particularly from the viewpoint of attempting to simulate the natural processes which originally turned organic matter into oil and natural gas.

c. Landfilling and Stockpiling

This method of disposal of organic sludge solids is another recognized and significant alternative (Refs. 6, 9, 24, 31, 36, 128, 154). It applies to at least partially dewatered organic solids and more often to dry and well stabilized organic solid residue. Digested and air dried, dewatered organic sludge reportedly consolidates rapidly (Ref. 24).

Specific Site Criteria. Landfilling involves the deposition of waste materials within reasonably well defined areas or in natural depressions without any subsequent placement of cover materials over the fill masses. Man-made depressions produced by quarrying, excavation for roadway fill materials, surface mining and similar activity can also be filled. The method is suited to areas with significant changes in topography or elevation and can be associated with some beneficial use. One early form of landfill disposal was the filling in of low-lying lands and swamps, particularly those near the sewage treatment works, with at least partially dewatered and partially stabilized sludge.

One form of landfilling and stockpiling employs permanent lagooning (Ref. 154). Permanent lagoons involve the deposition of sludge within a diked area. In some instances the sludge is never removed or may be removed for subsequent disposal only after several years. It is one of the least expensive methods of disposal where large areas are available at or near the treatment site and where climate allows its use. Design and location parameters include:

1) Land area - cost, availability, size, location
2) Climate - sunshine, evaporation rates, prevailing winds
3) Subsoil permeability
4) Lagoon depth
5) Lagoon sludge loading rates
6) Sludge and residual solids characteristics

Lagoons are often constructed over porous soils unless contamination of ground waters is a threat. Their construction and location is usually restricted so that their floors are at least 1.5 feet above the maximum water table elevation. Underdrains can be constructed to facilitate drainage of percolating sludge wastewaters. Estimated current combined capital and operating costs range between $2.00 and $7.00 per ton. Relative economics also seems to confine such landfilling generally to within 10 miles of the treatment plant site. When combined with municipal refuse, more ambitious landfilling projects can be considered, one example being the proposal to build up the surface elevations of many of the Delta islands which are now below sea level (Ref. 192).

Another form of landfilling is mass-fills associated with various construction projects. Organic sludge ash residues have some particular advantages in this use (Ref. 128). In England, compacted fly ash has been used routinely and apparently quite successfully for road subbases, load-bearing fills and lightweight backfills. Reported maximum compacted bulk densities range from 70 to 85 pounds per cubic foot. This represents a weight reduction of 30 percent or more over conventional earth fills. Ash residues with higher lime content have greater strength and durability when mixed with water and compacted. This higher lime content is associated with the use of lime to aid flocculation, dewatering and intra-secondary treatment phosphorus removal. Similarly, the City of San Diego (Ref. 196) in 1968 reported using well-digested sludges for a land reclamation project involving an undeveloped sandy island in Mission Bay. The sludges were pumped through a 7-mile pipeline to the island deposition area. Reported costs were $6.76 per dry ton, including depreciation of the pipeline and pump costs, plus labor, odor control and the spreading operation costs. They further reported that this cost drops to $4.65 per dry ton when the mass deposited increases from 8,400 to 18,300 tons per year.

Pretreatment and Deposition Rates. Some pretreatment operations have been inferred from the previous discussion. These operations cover the following range:

1) Digestion and thickening to at least 10 percent solids
2) Incineration and associated dewatering, drying and physical size reduction operations
3) Composting and associated preparatory operations
4) Sludge lagooning

Sludge lagooning as pretreatment for landfilling includes two types of operations:

1) Thickening, storage and digesting lagoons
2) Drying lagoons

Where land area and other factors permit their use, the first type of lagoon serves well as a secondary digester and for storage. As a storage facility, the lagoon can function as a separate drying bed (Ref. 9). Use as a secondary digester involves less chance of odor nuisance. Similarly, lagooning of ash residue combines storage, drying and, sometimes, filling, in one operation.

It has been estimated that, in the project year 2000, approximately 1.3 million cubic feet per day (9.43 MGD) of freshly settled and combined raw primary and secondary organic sludges will be produced in the entire 12-county waste source region, containing about 1570 tons per day of dry organic sludge solids. Digestion can reduce the dry mass to about 800 tons per day. Thickening to 10 percent digested solids will reduce the volume to about 257,000 cubic feet per day or 1.92 MGD. Air drying to 50 percent solids will reduce the volume to be handled to a compacted 53,400 cubic feet per day. Incineration can further reduce the dry mass to approximately 630 tons per day with a residual dry volume of about 18,000 cubic feet per day (667 cubic yards per day). Sludge lagooning can accomplish the same mass and volume reductions as cited for combined digestion and drying.

Estimating the mass and volume reductions of organic sludge by composting is more difficult because of the significant amounts of materials that are very often added to facilitate the process and because sludges are often combined with refuse in varying proportions in composting operations.

Based on the results of the Eimco Corp. - U.S. Public Health Service compost demonstration project (Ref. 114 and Section III-F-3), it is estimated that 1,270 tons dry solids or 1,720 tons total mass per day of aerobically composted material could be produced from the mixed organic sludges of the 12-county waste source region, in the project year 2000. This amounts to a volume of 71,500 cubic feet per day or 2,650 cubic yards per day. These values are based on assumptions 1, 3, 4 and 5 outlined in the first paragraph of Section III-G-6 together with an assumed bulk density of 48 pounds per cubic foot, a moisture content of 26 percent, an effective total dry solids reduction of 30 percent in the sludge feed, and a maximum chemical conditioner addition to the initial raw sludge solids of 15.5 percent. In unit terms, the

volume of compost amounts to 44.5 cubic feet per MG of raw influent or 302 cf/day per mg/l of influent Total Suspended Solids removed; the total wet mass amounts to 2,140 pounds/MG or 7.26 tons/day per mg/l of removed influent TSS; the total dry compost solids amounts to 1,580 pounds/MG or 5.36 tons/day per mg/l of removed influent TSS.

d. Dry Surface Spreading and Irrigation

Disposal by dry and wet surface spreading is related to the beneficial re-use of the processed waste organic sludges. The nature of the re-use and the type of spreading is dependent upon the pretreatment operations.

Pretreatment and Associated Methods of Application. Four basic pretreatment approaches are related to dry surface spreading and one for irrigation (Refs. 6,9,31,36,128, 154, 186, 200, 201, 209):

1) Digestion and drying, including the use of sludge lagoons
2) Filtration and heat drying
3) Composting
4) Incineration
5) Digestion, and perhaps composting for wet sludge spreading or irrigation.

The end products of the first three and the fifth approaches are used for agricultural, landscaping, land reclamation and related purposes.

The quantities of the various processed residual sludge solids in the project year 2000 are the same as developed in the previous sections.

Where construction and similar activites have produced a sterile or unproductive topsoil, the use of sludges is usually cheaper than importing topsoils for restoration purposes.

The restoration can involve both wet and dry applications. Related is the specific use of sludge to produce topsoil for urban landscaping, garden and park development, lawn and park maintenance and other purposes. One East Bay firm is currently taking 90 tons of dewatered sludge per day from the East Bay Municipal Utility District's West Oakland treatment works for this purpose (Ref. 207). The processing involves mixing the dewatered primary sludge with sand obtained from various local maintenance and dredging operations together with peat moss dredged from a site in the Delta and then curing

the mixture. The quality of the soil-like end product is attributed to EBMUD's use of polymers instead of ferric chloride or lime to coagulate the sludge.

The end product of incineration is used both in construction and agriculture. The ash is used as a filler in asphalt mixes, concrete additives and soil stabilizers. As noted in the previous section, organic sludge ash residues with a higher lime content have greater structural properties with respect to strength and durability when mixed with water and compacted (Ref. 128). Experiments are currently underway to combine fly ash from coal burning, calcium sulphate sludges from several industrial processing operations and hydrated lime into a "supersludge" paving material (Ref. 208).

Digestion and drying are the predominant processes currently used on sludges utilized for dry application on agricultural lands. Several months of additional storage of even well-digested and air dried sludges results in a more complete stabilization of the organic matter and therefore reduces the fly and odor nuisance problems occasionally developed. Sludge is considered fully stabilized when 75 percent of the organic matter measured as total volatile solids (TVS) is "destroyed" (Refs. 31, 200). The enhanced stabilization is made more effective if the material is shredded prior to curing and storage. Informal California State Public Health guidelines urge at least 30 days of digestion for dry or wet sludges intended for fertilizing vegetable, berry and low-growing fruit crops (Ref. 186). These guidelines also urge that the sludge be practically odorless, drain easily and have a volatile solids concentration under 50 percent. It is also considered advisable (Ref. 186) that digested sludge intended for use on vegetable and low-growing crops either be incorporated in the soil several months before the crop is grown or heat treated. Aerobically digested sludges exhibit fewer opportunities for nuisances. Shredding and grinding also facilitate dry spreading and destroying some weed and vegetable seeds. Mixing with compost enhances the value of the materials for mulching and as a soil improving agent. Dry sludges are spread like farm manure, turned under or harrowed before the crop is planted.

Raw sludges are generally not allowed to be applied on agricultural lands because of the public health hazard associated with the pathogenic organisms present. Its physical structure and grease content also diminish its value as a fertilizer. Heat dried waste activated sludge is the exception. Its higher nitrogen content (reportedly 4 to 5 percent) makes it more valuable. The heat drying or treatment process presumably kills the pathogenic organisms and parasitic worms and eggs that often survive secondary biological treatment processes. Aerobic composting

is an alternative because it is, in part, a heat treating and pathogenic destroying process. Thermal destruction of pathogens requires that a temperature level of 140°F be maintained for 40 hours. "Compact composting" followed by windrow composting can accomplish this (Ref. 186). Dry surface spreading has the advantage of involving the largest degree of volume reduction.

Wet surface spreading and irrigation eliminates the need for drying beds and other solid-liquid separation operations. This reduces the cost of handling and helps to avoid many odor problems. Substantial digestion, however, is usually required if nuisances in general are to be avoided and to increase the margin of safety from a public health standpoint. Post-digestion lagooning may also be required in order to increase the degree of stabilization outlined in the informal California guidelines (Ref. 186). Such lagooning or holding reservoirs have been found effective in reducing nitrogen levels when the nitrogen content was a limiting factor (Ref. 201). Lagoons also provide storage close to the ultimate areas of use. As a general policy, about one year's storage capacity should be provided in the sludge management system. Wet application and irrigation methods include the following: (Refs. 6, 7, 9, 24, 21, 36, 154, 186, 200, 201, 209, 210).

1. Pumping or gravity feeding through pipelines or channels to agricultural fields, lands to be reclaimed and other areas. The customary range of irrigation methods and "engineered soil systems" can be employed (see Technical Appendix Volume II). The only special consideration concerns the problem of clogging and deposition due to the high suspended solids content of wet sludges. Where spray irrigation is employed, grinding of the solid material in the wet sludge may be required. Furrow irrigation is reportedly preferred to spray irrigation for aesthetic reasons (Ref. 209).

2. Injection into the subsoil under pressure, as is done at some orchards.

3. Spraying directly from tanker trucks or tanker wagons. This approach becomes costly when truck hauling distances are greater than 10 miles (Ref. 186).

4. Conventional irrigation spreading followed by discing or harrowing. This is a three-step procedure involving spreading of a shallow layer of sludge, drying and harrowing. A deeper layer of sludge is then applied with subsequent drying and harrowing. Such multiple applications at low dosages form a thin sludge layer that is easily worked into the soil. In New York, the method involves drying

for two to three days after initial distribution followed by discing, with the procedure repeated about 16 times until four inches of topsoil are formed from a mixture of sludge and sand. At San Diego, furrows were plowed in sandy soil, filled with sludge and immediately covered. This was followed by drying for one to two weeks, subsequent plowing of cross furrows and the repeating of the procedure.

Value as a Crop Supplement. Municipal wastewater organic sludges are considered to have value as a fertilizer and soil conditioner when properly processed and applied to the land (Refs. 6, 9, 24, 36, 154, 186, 196, 201, 209). They have demonstrated their usefulness as a fertilizer for agricultural crops, grasses, shrubs and as a soil conditioner for relatively sterile dredged sand. Compost, in particular, has superior soil conditioning characteristics.

The use of dried digested sludge has reportedly achieved good results with citrus, tobacco, cotton, corn, potatoes and cabbage crops and with various grasses. Increases in yields up to 18 percent over unfertilized crops have been observed. Limited investigations in Connecticut indicate that sandy soils benefit more than loams (Refs. 154, 186) with field moisture capacity, non-capillary porosity and cation exchange capacity increasing by 3 to 23 percent, soil organic matter increasing by 35 to 40 percent, total nitrogen increasing up to 70 percent and soil aggregation increasing from 25 to 600 percent. The best results can be achieved when these sludges are used in combination with inorganic fertilizers. Well digested sludge, when properly applied, can reduce storm and irrigation runoff because of its moisture holding capacity. This reduces soil erosion on slopes and aids in reducing silt and turbidity loads in adjacent water bodies. Sludge mulches can also reduce pollution of groundwaters from acid and fertilizer leachate, and toxic pesticides and herbicides because of absorptive and retention capabilities and the ability to utilize or decompose such substances. The labor and trucking costs associated with making and using dried digested sludges together with their low fertilizer value limit their use at greater distances from treatment plant sites. However, continuous high-value cash cropping which requires soil amendment increases the value of the soil conditioning properties of these sludges and therefore may justify their use at greater distances from treatment plant sites. Good examples of such cropping include commercial nurseries, flower and vegetable cultivation, orchards and vineyards. The addition of lime to dried digested sludges is recommended if no lime has been added during the conventional secondary treatment processing. Lime neutralizes excess acidity, precipitates some metals that may be present in excess concentrations and encourages bacterial decomposition of organic solids. Lime also improves the physical structure of heavy

soil supplies needed calcium and assists in making phosphorus and nitrogen available for plant growth.

In San Diego, experience with wet digested sludges and various application rates indicates that, with an application rate of 25 tons per acre, crop growth can be achieved which is equal to that from the use of commercial fertilizers applied at conventional rates. Superior crops can be produced over a two year period using 50 tons per acre the first year and none the second.

In Chicago (Refs. 200, 201, 212), two inches* of digested sludge was found to satisfy the nitrogen requirements of non-leguminous crops without producing excessive nitrogen in the drainage water. At approximately 3 percent solids (6.85 tons total solids/acre/year), this sludge application amounted to about 225-250 lbs/acre of NH_4-N, about 300 lbs/acre organic-N, 200-300 lbs/acre of phosphorous (80 percent of which was organically combined) and 40-80 lbs/acre potassium. The two inch application rate increased corn production by 36 bushels per acre. An average corn crop reportedly required 150 lbs/acre N, 40 lbs/acre phosphorous and 80 lbs/acre potassium. Higher total solids loading would require further pretreatment for reduction of N levels (by interim lagoon storage, for example) and/or denitrification of drainage waters. Corn has been estimated to remove about 1 pound of nitrogen from the soil per bushel, soybeans about 3.85 pounds per bushel and alfalfa about 56.7 pounds per ton of dry weight; higher removal rates thus being proportionate to higher crop yield rates. Analyses of key nutrient components in Chicago's 2-1/2 to 3 percent total solids digested sludge indicated total nitrogen content of 5 to 6 percent of total solids (50 to 76 percent suspended, the organic-N fraction, 24 to 50 percent dissolved, the combined ammonia and nitrate-N fraction), a total phosphorous content of about three percent of total solids (93 percent suspended), and a total potassium content of 0.6 percent of total solids (about 8 percent suspended). About 3 percent of the total sludge solids were in the dissolved state.

The major sludge nutrients are calcium, magnesium, potassium, nitrogen, phosphorous and sulphur. Minor and trace-quantity nutrients include iron, copper, boron, zinc, manganese, molybdenum and chlorine. Other important elements are chlorine, iodine, flourine and sodium. Organic sludges are rated for their fertilizer value primarily in terms of three constituents: nitrogen, phosphorous as phosphoric acid (P_2O_5) and potassium as potash (K_2O). Nitrogen is important for leaf and stem growth. Phosphorous is important for roof growth, ripening and resistance to plant disease. Potash is important for vigorous growth, the development of the woody parts of stems and the pulp of fruit, the

* 0.167 acre-feet/year

formation of chlorophyll and resistance of plants to disease. Humus content is important for water-holding capacity, soil erosion resistance, as a substrate or medium for soil bacteria to make nitrogen available for plant growth and otherwise contributes to soil fertility.

The principal fertilizer and soil conditioning chemicals and materials in sludges are reported in terms of percentages of the dry total solids. The following ranges of values have been observed in the literature (Refs. 6, 9, 24, 36, 111, 123, 128, 154, 186, 196, 216).

1. Total Nitrogen. 0.8 to 5 percent is reported for raw primary sludges, 2.5 to 10 percent for raw activated sludges (secondary sedimentation tank sludges), approximately 0.4 to 3 percent for digested primary sludge, somewhat higher values for heat dried sludges, 1.5 to 5 percent for digested activated sludges and approximately 4 to 6 percent for heat-dried digested activated sludges. Digestion tends to reduce the nitrogen content as much as 40 to 50 percent, principally by the production and loss of nitrogen gas and possibly some ammonia. It should be noted that nitrate nitrogen is the form most available for crop uptake, ammonia nitrogen is less available and organically combined nitrogen is least available.

The total nitrogen content of the raw mixed organic sludges from the 12-county waste source region, in the year 2000, would be about 15 percent of the total dry solids, assuming (1) the concentration of the combined municipal and industrial wastewaters projected in Technical Appendix Volume II, (2) assuming the 30 percent removal of total nitrogen in the secondary treatment process and (3) assuming further that all removed nitrogen would be in the organic sludges. From the previous discussion, it is estimated that digestion would reduce this initial nitrogen content by 32 percent. The estimated concentration of total nitrogen in the digested sludge is 20.6 percent of total dry solids.

2. Phosphorous (P_2O_5). A range for raw sludges is reported as 1 to 3 percent. Various specific information indicates 1 to 5 percent for raw primary sludges, 2 to 11 percent for raw activated sludges, 0.5 to 5.6 percent for digested sludges. Digestion or heat drying reportedly tend to increase the percentages of those of raw sludge, although many reported analyses do not support this. Fluid bed incinerator organic sludge ash values have been reported at about 5 percent while those for multiple-hearth organic sludge ashes range from 3.86 to 15.35 percent P_2O_5. There are some indications that mixing organic ash residues with digested sludges would increase the phosphorous content somewhat.

The total phosphorous content of the raw mixed organic sludges from the 12-county waste source region, in the year 2000, is estimated to be about 6.6 percent as P_2O_5 of the total dry solids. This assumes (1) the concentrations of the combined municipal and industrial wastewaters projected in Technical Appendix Volume II, (2) the estimated 30 percent removal of phosphorous in the secondary treatment process and (3) that all the removed phosphorous is in the organic sludges. Assuming further that no phosphorous is lost in the various sludge volume reduction processes, it is estimated that the P_2O_5 content of digested sludge would be about 13.2 percent of the total dry solids while that of the incinerated ash residue would be about 26.4 percent.

3. Potash (K_2O). 0.1 to 0.8 percent has been noted without referring to the type of sludge. 0.9 percent has been reported (Ref. 123) for an activated sludge while 0 to 4 percent has been reported for digested sludges. 1.4 percent has been reported (Ref. 117) for the ash from a fluidized bed incinerator and 0.07 to 0.66 percent has been reported for various organic ash residues from multiple-hearth units.

4. Humus. 33 percent has been reported for fresh sludges, 35 percent for digested sludges, 41 percent for activated sludges and 47 percent for trickling filter sludges.

The following table illustrates the comparison between the principal nutrient concentrations found in commercial fertilizers, Chicago digested sludges (Ref. 200) and the estimated concentrations in Bay-Delta digested sludges in the year 2000:

Commercial fertilizers	20% N	10% P_2O_5	10% K_2O
Chicago digested sludges	6% N	3%	0.6%
S.F. Bay-Delta digested sludges	20.6%	13.2%	?

The above indicates dramatically that the projected increases in the nitrogen and phosphorous inputs to the regions wastewaters would produce sludges with nutrient values about equal to or better than those in commercial fertilizers assuming the continuation of current normal secondary effluent and sludge treatment processes. These projections should be severely reviewed.

From the foregoing analysis, it seems clear that appropriately processed organic sludge solids can be of value to almost any type of crop. However, the details of this kind of determination depend upon the specific circumstances and in most cases, field experimentation.

Public Health Hazards. The presence of pathogenic organisms presents the most serious potential problem with land spreading of wet or dry sludge (Ref. 186). Wet sludges are more of a problem in this respect because they may contain more pathogens and because the greater possibilities of percolation and leaching make the contamination potential more immediate. Therefore digestion and heat-drying for dry application methods and digestion and lagoon storage for wet application methods are recommended to reduce the indicator fecal coliform populations down to safe levels. As indicated previously, operational procedures can be employed which accomplish the equivalent of substantially advanced stabilization and natural disinfection. The importance of this pretreatment is related, in part, to the air-borne contamination potential (Ref. 211). In spray irrigation, for example, 5 to 30 percent of the liquid can be transported away by light winds. Any pathogenic organism or toxic substances in these air-borne liquids thus become more readily available for adsorption by plants, animals and man.

The input of industrial wastes into municipal systems constitutes another source of public health hazards and may alter reuse approaches to de-emphasize the fertilizer uses of these sludges because of the heavy metals involved (Refs. 186, 211). Lisk, reported that edible plants raised on treated sewage sludges contained heavy metals (specifically mercury, cadmium, lead and arsenic) at concentrations possibly toxic to humans. The chief input of these heavy metals is suspected to be industrial waste. The whole subject, however, needs much further investigation. The evidence concerning toxicity to humans is far from conclusive. The heavy metals uptake may concentrate in parts of the plant not consumed. Zinc, for example (Ref. 200), in the case of corn is found mostly in the leaves. This latter pnenomenon may provide a basis for removal of some heavy metals from the soil.

These public health hazards can be mitigated substantially by the following procedures:

1. Choosing sites with soils and subsoils that act as a fine filtering medium. One to six feet of soil depth has been reported as necessary to "equilibriate" specific inorganic elements (Ref. 211) while two to five feet were found to have "good" treatment efficiencies on organic and related inorganic substances (Ref. 199). In the latter case, five feet was found to be optimal when "hydraulic longevity" was a factor. Chemical Oxygen Demand (COD) removals ranged from 83 to 88 percent, MBAS (a measure for detergents) removes between 71 and 78 percent and ammonia nitrogen removes between 87 and 99 percent.

2. Use of properly located and designed sanitary landfills (discussed in a previous section).

3. Use of greater degrees of sludge pretreatment or longer periods of sludge storage.

4. Emphasis on keeping heavy metals and other toxic substances out of the municipal system. This procedure is currently being emphasized in California through industrial wastewater control ordinances.

Application Rates. The following values indicate the various amounts of differently processed organic sludges that would be produced in the project year 2000 assuming all the organic sludges produced in the entire 12-county waste source region were so processed:

Table III-G-6
ESTIMATED QUANTITIES OF DIFFERENTLY PROCESSED ORGANIC SLUDGES FOR THE YEAR 2000 - 12-COUNTY WASTE SOURCE REGIONAL TOTAL

Type of Pretreatment	Thousands Cu.Ft./day	MGD	Dry Tons/day
Wet Digested (@ 5% solids)	514	3.85	800
Dewatered Digested (@ 10% solids)	257	1.92	800
Dry Digested			
@ 50% solids, uncompacted bulk density of 22 lbs/cu.ft.	147	1.1	800
@ 50% solids, compacted bulk density of 60 lbs/cu.ft.	53.4	0.4	800
Composted	71.5		1270

Burd (Ref. 154), in his 1968 survey of dry sludge application rates, observed that between 10 to 40 dry tons per acre per year are recommended. The upper limit of application is determined by the toxicity due to the trace elements in the sludge. If the sludges have been produced from treatment works not employing lime in chemical conditioning, it was further recommended that the soils to be fertilized with dry sludges be limed in the fall before the sludge is applied, this at rates between 0.5 to 1 ton per acre. A survey of more recent

literature reveals no significant change in those amounts. It is worthwhile to note that the success of Chicago and Milwaukee in marketing their dry sludges is due in part to the relatively high nitrogen content of these sludges, this last being an objective of the design and operation of the treatment works. Between 1944 and 1956, San Diego's processing costs for bagged heat-dried digested sludge went from $24 to $44 per ton.

As of 1968, wet sludge application rates reportedly ranged from 0.5 to 500 tons dry solids per acre per year in slurry concentrations varying from 1 to 10 percent solids (Ref. 200). 0.5 to 50 dry tons per acre per year (dTpapy) represent annual loadings in conjunction with farming; 50 to 500 dTpapy represent massive one-time applications on sterile soils, with the extremely heavy rates (over 200 dTpapy) being confined to dredged coastal areas where groundwater pollution is no problem. At San Diego (Ref. 154), a reclamation project involved an application rate of 1000 dTpapy. A California state-wide survey of applications on cropland indicated that 100 dTpapy was "successful under average conditions" (Ref. 154), while 300 dTpapy was found to be "practical" in areas of low rainfall. It should be noted that little investigation of leaching consequences was made. In 1968 (Ref. 154), liquid sludge disposal on land (excluding digestion) cost between $4 and $30 per ton of dry solids, the average being $10 per ton.

Reported experiments (Ref. 198) indicate that up to 30 dTpapy of organic-carbon produce up to 3 tons per acre per year of accumulating soil residue. This is considered no problem. This loading is about equal to 100 dTpapy of total dry digested sludge solids. Silty-loam type soils were found to require a minimum loading of 2 to 5 dTpapy organic-carbon in order to maintain a static organic concentration in the soil. Frequent additions and small additions produced the greatest rate of biodegradation.

Specific application rates at San Diego have been mentioned in a previous section (Ref. 154). 100 dTpapy was applied to cropland without impairing the growth of the crops. 25 dTpapy produced a growth equal to that from using commercial fertilizers at conventional rates. 50 dTpapy produced superior crops over a 2-year period where the sludge was not applied the second year.

At Chicago (Refs. 200,201, 209), a cropland application rate of approximately 20 dTpapy was reported, the average first year rate being about 125 dTpapy. This 20 dTpapy rate was set by nitrogen constraints. Sandy soils would allow the greatest degree of nitrogen leaching because they are unable to store excess soluble nitrogen (Ref. 200)

All available nitrogen not removed by denitrification or crop uptake would leach out. An approximate materials balance assuming idealized conditions (in an otherwise very complex one) indicated the following:

1) With a nitrate concentration in the leachate being held to 45 mg/L, the drinking water standard, the application rate would have to be limited to 5.1 dTpapy (560 lbs-N/acre/yr) assuming all organic N held, and 1.6 dTpapy (220 lbs-N/acre/yr) assuming all organic N leached.

2) With a fixed application rate of 20 dTpapy (2010 lbs-N/acre/yr), the leachate concentration would be 900 mg/L assuming all organic N held, and 3560 mg/L assuming all leached. This latter high leachate concentration could be obtained over an 18-year period.

3) The annual loading rate of 20 tons/acre, therefore, is considered possibly somewhat high, unless all organic N is retained in the soil or greater crop removals are obtained. It was noted that researchers differ markedly in their estimates of nitrogen mineralization rates, crop removal potential and nitrogen retention in soils.

If the nitrogen concentration for Bay-Delta region digested sludges holds to the projected 21 percent level discussed in the previous "value as crop supplement" section, then the application rate for the Bay-Delta region equivalent to Chicago's 20 dTpapy would be 5 tons/acre/year.

The 1968 cost of this operation was about $25 per ton. $8.80 to $10.90 per ton covered the costs of the operation and maintenance of the sludge and irrigation distribution system and the capital costs of the land, pipeline, pumping facilities and farm development, based on 6 percent interest and an amortization period of 50 years. Information concerning industrial wastewater sludges revealed, for example, that an application rate of 20 to 25 dTpapy was feasible for a dilute paper-mill sludge (high in cellulose) while a whey waste (5 to 6 percent total solids) could be applied at rates not exceeding 50 dTpapy and still have increasing crop yields.

The following table demonstrates the relation between a range of dry and wet application rates and the amount of crop acreage

required to accept these loads at the rate digested organic solids are expected to be generated in the project year 2000.

Table III-G-7
WET DIGESTED ORGANIC SLUDGE SPREADING RATES AND RELATED ACREAGE REQUIREMENTS
12-COUNTY WASTE SOURCE REGIONAL TOTALS FOR THE YEAR 2000

Application Rate						Required acreage to accommodate 800 dry tons per day of digested organic sludge solids
Dry Tons/acre/year			%	Feet	Gals/	
Total Solids	Total Nitrogen	Total P_2O_5	Total Solids	per year	Acre/ year	
5	1.0*	0.7*	5	0.074	24,000	58,400
5	1.0*	0.7*	10	0.037	12,000	58,400
20	4.1*	2.6*	5	0.294	96,000	14,600
20	4.1*	2.6*	10	0.147	48,000	14,600
30	6.2*	4.0*	5	0.442	144,000	9,733
30	6.2*	4.0*	10	0.221	72,000	9,733
50	10.3*	6.6*	5	0.736	240,000	5,840
50	10.3*	6.6*	10	0.368	120,000	5,840
100	20.6*	13.2*	5	1.472	480,000	2,920
100	20.6*	13.2*	10	0.736	240,000	2,920

* From previous sub-section "Value as a Crop Supplement"

The actual application rates will have to be determined in the field. The factors governing the optimal application rate are sufficiently complex to rule out any simple theoretical approach. The problem of balance is of utmost importance in topsoils (Ref. 186). Too much incompletely stabilized organic matter in the soil puts pressure on the soil microbiota's ability to stabilize this material. A modest overloading will therefore delay the availability of nitrogen for plant growth. Consequently sustained modest overloadings are questionable and should be avoided. Ideally, the application rate should be suited to the soil and the crop in such manner that the applied nitrogen will just satisfy the crop's requirements and none will be left for leaching downward into the groundwater basin.

The foregoing discussion appears to indicate that the application rate on a dry weight basis for a given crop under given circumstances will be about the same whether the application is made with dry or wet sludges. The information available indicates no significant difference. For estimating purposes, the value of five tons per acre per year is recommended so long as current nitrogen concentration projections hold.

Water Quality and Environmental Impacts. The most significant effect on water quality from both the dry and wet land application of sludges is due to the leaching of dissolvable solids into the groundwater basin and adjacent surface waters. Some increase in mineralization and total dissolved solids (TDS) is to be expected. It has been observed (Ref. 210) that domestic use adds approximately 300 mg/l of TDS to water. It has been assumed that no TDS is effectively removed by secondary-level treatment processing. The TDS in the liquid part of wet sludges can be assumed to behave in the soil in the same manner as TDS in treated wastewaters. This subject is covered in the wastewater Technical Appendix Volume II. The extensive environmental impact assessment of wastewater applications made in Volume II apply to irrigation with wet sludges with equal force.

It is roughly estimated that the total dissolved solids in a 5 percent wet digested sludge will range between 900 and 3900 mg/l. Total dissolved nitrogen will account for 375 to 1800 mg/l. Total dissolved phosphorous will account for 60 to 100 mg/l. The expected 85 percent removals of nitrogen and 99 percent removals for phosphorous with spray irrigation techniques could produce initial leaching concentrations of 55 to 270 mg/l of nitrogen and 0.6 to 1.0 mg/l of phosphorous, depending upon the interrelations between application rates, soil types and crop cover. The liquid fraction of sludge has the characteristics of a concentrated secondary effluent. If the hydraulic loading on land was the same as used in wastewater irrigation, one could predict higher concentrations in the leachate. However, the effective solids loading is such that the leachate is substantially similar to that produced with secondary effluent.

A 40 percent removal of gross heavy metals in the secondary level treatment process is assumed. Therefore about 10 tons per day (in the year 2000) will be removed with the wastewater residual solids and it is further assumed that all of it will be in the organic sludges. Several studies (Refs. 200,201) indicate that these heavy metals are usually in the solid state and normally remain in the plow layer after land application, along with the sludge residue. Their solubilization is considered negligible in soils of neutral of high pH. The heavy metals are normally tied up chemically with the soil minerals. At

Chicago (Ref. 201), plant uptake of zinc, manganese and iron was found to be generally enhanced by sludge application. The studies indicated, however, that this enhanced uptake was not altogether the result of direct heavy metals additions with the sludges but rather due to induced mobility of native metals. These studies showed no uptake of cadmium or chromium and only occasional uptake of lead. In the year 2000, gross heavy metals inputs could range from 126 to 2500 pounds per acre per year within the range of application rates 5 to 100 dTpapy. This assumes no significant loss through plant uptake which, if significant, would present public health problems. The immediate effect through leaching, therefore, is expected to be slight. The buildup of heavy metals concentrations at year 2000 rates is not as great as it would appear since they are in complex with the remainder of the organic sludge residue that is applied. Nevertheless, the tendency toward buildup is a concern. Further attempts at reducing heavy metals inputs into the public system must be made along with the development of unit operations or processes designed for specific removal of these metals. Another approach is the isolation of certain sludges for different modes of disposal. The heavy metals concentrations vary from county to county. The higher heavy metals containing sludges can be incinerated and the ash residue buried in a Class I site.

There are no general limitations on using the same facilities for the transportation of sludges and wastewater for irrigation. Digested sludges and composts can be slurried in treated wastewaters to facilitate distribution. Soil, standing crop or vegetation requirements and measures necessary for the protection of adjacent ground and surface waters will impose definite limitation on solids and nutrient loadings. At Chicago, for example (Ref. 201), sludge irrigation rates were limited (20 dry tons per acre per year) by nitrogen concentrations and not heavy metals contents, as might be expected. High concentrations of heavy metals or other potentially toxic substances in sludges may, however, impose specific limitations on the possibilities of irrigating the same areas with both sludges and wastewaters from the same plant. Care must be exercised to assure that potentially dangerous materials removed from wastewaters will not reappear in sludge applications.

Other leaching problems can be mitigated by controlling sludge application rates and crop selection, and by modifying treatment operations. Near optimal removals of various dissolved constituents are possible and are discussed in Volume II dealing with removal efficiencies. Land spreading is a special form of "engineering soils system" where emphasis is on the vegetative cover (Refs. 7, 210).

Another important environmental impact of land application of sludges results from the interaction between sludge and the soil system. Although the information is somewhat speculative, there are indications that the long-term effects of sludge application will include (Ref. 200):

1) Improvement of the soil structure by increased aggregation.

2) Increased permeability of fine textured soils resulting from increased concentrations of fine particles.

3) Decreased permeability of sandy soils resulting from increased concentrations of fine particles.

4) Some increase in available moisture holding capacity of sandy soils.

5) Decreased erosion hazards.

6) Increased absorptive capacities.

7) Decreased permeability of sandy soils and increased leachate nitrate concentrations with continued applications at high rates (about 20 tons/acre/year). Increased leachate nitrate concentrations would result from gradual exhaustion of the soil storage capacity (usually the first 30 inches having an organic-nitrogen holding capacity of 10,000 to 20,000 pounds per acre).

For a somewhat more expanded summary, see Table III-G-8.

Water and environmental quality problems potentially associated with land application of sludges can be mitigated through comprehensive management and control programs. Procedures outlined in Section G in Volume II of this report for the management of potential wastewater application sites also apply to proposed sludge application programs, and include:

1) Provision of corridors to isolate application areas from the public and public surface waters.

2) Daily sampling and analysis of reclaimed waters.

Table III-G-8

EFFECTS OF SLUDGE APPLICATION ON SOIL

Physical Effects

Property	Sand Soils	Silty Clay Loam Soils
(1) Soil Structure		
Degree and type of aggregation	Slight improvement owing to some aggregation of particles from cementation by organic compounds.	Moderate improvement due to aggregation of clay particles makes soil more friable, less cloddy. Stability of aggregates will be greater.
(2) Infiltration Rate		
Penetration of water into surface soil	Decreased rate owing to addition of fine particles and grease from sludge.	No change or increase owing to improved aggregation.
(3) Permeability		
Movement of water within soil	Decreases permeability if sludge mixed into soil - if placed as a layer may cause temporary perching of water.	Increases permeability if sludge mixed into soil.
(4) Maximum Retentive Capacity - Percent H_2O at saturation	Increases substantially, e.g. 30% to 50%	No change or may decrease slightly.
(5) Available Moisture Capacity - Moisture available to plants	Increases somewhat - field capacity (1/3 atm.) is increased substantially but wilting coeff. (15 atm.) increases proportionately so net gain in available moisture is not great.	No significant change - or slight increase.
(6) Free Water		
Superfluous to plant needs.	No effects if under-drainage is provided.	May cause brief periods of water logging even though under-drainage is provided. Dependent on loading rate of the wet sludge and timing of application.
(7) Trafficability		
Vehicular traffic on field surface.	No change or delay due to sludge application.	May delay traffic over field for 2-3 days depending on rate of sludge application and natural rainfall.
(8) Susceptibility to Wind and Water Erosion		
Assuming no cover crop.	No appreciable change or may be somewhat less susceptible to wind erosion, particularly if sludge applications are frequent enough to keep surface moist.	May lessen water erosion by increasing infiltration rate.
(9) Soil Texture	It is assumed that a substantial part of the insoluble ash in sludge is of silt and clay size (<50 microns). Therefore, it is expected that an admixture of 10T. sludge (or about 2-3tons ash) per acre per year will gradually produce a finer textured soil. For example, a loamy sand may be changed to a sandy loam.	The effect of sludge on silty clay loam soils would tend to coarsen the the texture somewhat.

(Ref. 200, Exhibit C-9)

Table III-G-8
(cont.)

Chemical Effects

Property	Sand Soils	Silty Clay Loam Soils
(1) Cation Exchange Capacity (CEC). (Also buffering capacity or resistance to pH change)	Should increase substantially, sandy soils have CEC of about 5 meq/100g., with sludge it might be increased to 10 to 15 assuming organics in sludge are comparable to soil humus which has a CEC of about 150.	May increase somewhat - clay component in these soils and native organic matter have CEC's of from 20-40 meq./100 g.
(2) Exchangeable Cations	The normal order of abundance of exchangeable cations held on exchange sites of Illinois soils is Ca > Mg > K > Na. This is determined by factors other than soil texture. The order of abundance in the sludge is the same although the proportions may be quite different than in soils. Assuming that these elements are in ionic form (readily dissociated salts) it does not appear that sludge applications to soils will upset the balance of exchangeable cations except that occasionally Na may surpass K in abundance. This probably will not have any serious side effects, i. e., Na should not become so abundant on the exchange sites of clay particles as to cause dispersion("puddling"), also, K can be readily applied as a commercial fertilizer should it become a limiting plant nutrient.	
(3) pH	Owing to the high pH of sludge (7.0 - 7.5) and the low buffering capacity of sands the pH should be increased to near neutrality in a short period of time.	Sludge will increase pH but the change will be more gradual than in sands; also greater amounts of sludge would be required to cause changes in pH comparable to those in sands.
(4) Ability to Adsorb Heavy Metals (Cu, Zn, Ni, Pb, Cr, Mo,	Sands in original condition have virtually no capacity to adsorb heavy metals. Any adsorption capacity for heavy metals would be associated with the sludge itself. It is not known at this time to what extent this capacity is saturated with respect to the heavy metals already present in the sludge. Research is needed to determine this.	Soils with fair amounts of silicate clays (montmorillonite, vermiculite, and illite) have a fairly high capacity to adsorb heavy metals. However, little is known about the long term effects, e.g. Is the adsorption capacity saturated with respect to Cu, Zn, etc., in a few years, in a hundred years of continued sludge application?
(5) Ability to Adsorb Ammonium Ion.	Sands have no ability to adsorb ammonium ion. The addition of sludge will increase the adsorption capability of the soil-sludge mixture.	It is reported that as much as 50% of the total N present in certain illite-containing soils has been found to be in the "fixed" ammonia form*. In this fixed form, the nitrogen is not subject to rapid oxidation, although in time it may become available.
(6) Ability to Adsorb Phosphates	Sands have little or no ability to adsorb phosphates. Adsorption of phosphates will be related to organic matter content. From the standpoint of Phosphate-fertility the addition of sludge should therefore be quite beneficial on sandy soils, particularly since Ca is also added and the pH of the sludge is near neutral to slightly alkaline.	As in the case of sandy soils much of the soil phosphorous in silty clay loam soils is associated with the organic matter. Although the anion adsorption properties of the chief clay minerals present in Illinois soils are low some adsorption of this type will undoubtedly take place. Also, if soil pH is acid, fixation of phosphorus by Fe and Al compounds will take place (most of these compounds occur in the clay fraction); at alkaline pH values phosphates will be precipitated as Ca-phosphate.

Table III-G-8
(cont.)

Bacteriological Effects

Property	Sand Soils	Silty Clay Loam Soils
(1) Bacteria Population	Owing to the droughty nature of sand soils organic residues are quickly oxidized. Hence, existing populations of microorganisms are generally quite low. The addition of the organics in the sludge to sand soils may increase existing populations as well as introduce new colonies and species. California data 1/ suggest that a 10 to 50 fold increase in bacterial populations in sandy soils from sludge application may be expected. A pH increase to about neutral due to sludge application may further stimulate bacteria growth.	Good agricultural soils with moderate moisture holding capacities and fairly high organic matter contets usually carry a great number of microorganisms. Populations introduced with the sludge and the addition of organic materials in the sludge may or may not increase bacteria populations. The possibility exists that the competition between various kinds of microorganisms may depress total populations; also certain inorganic substances, e.g., copper salts may act as bactericides. It is likely that sludge applied to the silty clay loam prairie soils of Illinois will not be beneficial to soil bacteria either in kinds or numbers.

1/ Report on Continued Study of Waste Water Reclamation and Utilization. State Water Pollution Control Board. Sacramento, California, Publication No. 15, 1956.

3) Periodic sampling and analysis of vegetation to determine uptakes of constituents.

4) Fencing of application fields, reservoirs and open canals.

5) Careful management of application systems to include the timing of applications to minimize health hazard opportunities and the control of loading and resting cycles to maximize soil filter life and efficiency.

The "Basin Plan" (Ref. 201) proposed for Chicago's sludge irrigation project incorporates environmental control features, including:

1) Moderate reforestation and restructuring of farming techniques to effect multipurpose land uses including open space, recreation, flood control, conservation and agricultural uses.

2) The use of buffer zones to provide open spaces and consist of:

   a) Heavily wooded strips between fields and roadways, and between fields and adjacent channels or streams.

   b) Hedgerows between fields.

3) The incorporation of downstream retention ponds for further denitrification of drainage waters and for pollution control monitoring.

It is thought that root systems of hedgerows and wooded buffer zones will provide a "natural filtering system" for drainage waters that are restricted by impervious subsurface strata and flow horizontally. The use of these hedgerows and buffer zones appears to be particularly suitable for areas where groundwater basins are not extensive and most of the wastewater is recovered in surface channels. In addition, it is thought that expected plant and animal life in these hedgerows and buffer zones will eliminate or reduce the need for chemical insecticides.

Specific Site Criteria. The following criteria for selecting areas for land spreading application closely parallel the wastewater site identification criteria (Section II-D-1).

1) All lands having elevations greater than 1500 feet should be excluded where pipeline transport of wet sludges to the sites is involved.

2) All land situated in national and state parks and national wildlife refuges shall be excluded, although this may be selectively reconsidered.

3) All lands projected to be in urban areas in the year 2000 shall be excluded where wet sludge irrigation and non-heat treated dry sludge spreading is involved.

4) All lands having soils classified as Group D by the Soil Conservation Service shall be excluded. Lands having an identifiable hardpan layer or bedrock at a depth of less than four feet from the surface will be excluded with specific exception being made for lands which can be successfully irrigated and drained.

5) Land application should generally be avoided in flood plains except where the application is considered highly desirable and the site can be protected from floods of a reasonable design frequency.

6) The selected areas should be located 10 and 15 feet above the water table.

7) The selected site must be situated so that no surface water can drain directly into any adjacent surface water bodies.

8) All lands of insufficient size relative to mode of land application, required pretreatment and distance from treatment plant sludge source shall be excluded.

The first and eighth criteria are based on economic considerations. The second criterion is presented because of legal and institutional considerations. As noted in Technical Appendix Volume II, this was waived in the case of Site No. 4. The third, fifth, sixth and seventh criteria are based on public health and water quality protection considerations.

7 - Land Disposal of Lime Sludges

Lime sludges can be an important removable solids fraction from the combined municipal and industrial wastewater process stream. Their production is contingent with the use of tertiary high-lime methods for the enhanced removal of phosphorous and residual organic material from secondary effluents. If all treatment plant operations, in the project year 2000, included high-lime tertiary processing, approximately 20 million gallons per day (MGD) of fresh lime sludges would be produced in the 12-county waste source region (Table III-G-1). This volume would contain about 4200 tons per day of dry solids. These values are based on the following assumptions:

1) The assumed projected wastewater flows in Table III-G-1 and II-B-10 and the assumed projected secondary effluent phosphorous concentrations listed in Table II-B-10.

2) A bulk density of 62.4 pounds per cubic foot at an assumed moisture content of 95 percent.

3) The use of the following formula: lime sludge solids in lbs/MG = 41.25 x 8.34 lbs/MG/mg/l/mg/L secondary effluent total phosphorous (Table II-B-10).

The average regional loading rate for freshly separated tertiary lime sludges was estimated to be 5160 pounds of total dry sludge solids/MG with the volume loading rate being about 1.24 percent of the influent wastewater flow rate. It would be more accurate to estimate the magnitude of lime sludges as a function of the alkalinity in the wastewater (Ref. 215).

From one-third to one-half of the dry total solids can be assumed to be lime as CaO (primarily in the form of $CaCO_3$ and secondarily as $Ca_5(OH)(PO_4)_3$). It can be further assumed that the other one-half to two-thirds of dry solids includes about 100 tons per day of phosphorous (based on 95 percent removal of secondary effluent phosphorous (Ref. 195). This would probably occur in the form of phosphorous sludge ($(Ca_5(OH)(PO_4)_3)$, at a rate of 667 tons per day. Assuming 70 percent removal from the secondary effluent (Ref. 195), 122 tons of suspended solids per day and about 216 tons of BOD would be included. The BOD indicates possibly as much as 1400 tons per day of putrescible organics have been removed. The remaining fraction of the dry solids includes various precipitated salts which contribute to alkalinity. The total dissolved solids are reduced to about 35 to 55 percent of initial secondary effluent levels.

Lime sludges are the most voluminous of the chemical sludges which can be produced with tertiary or "advanced waste treatment" generally and with tertiary treatment for phosphorous and residual organics removal specifically. Alum-iron sludges, for example would generally constitute less than half the amount of producable high-lime sludges. Only demineralization processes could produce sludges in amounts exceeding that of high-lime treatment, the degree depending upon the amount of Total Dissolved Solids removed. One mg/l removed equals 8.34 dry pounds per million gallons.

Lime sludges are subject to the same land disposal methods and associated pretreatment operations as organic sludges. In view of the volumes potentially involved, thickening, dewatering and drying operations will probably be necessary and they will produce the same corresponding reduction in volumes as indicated in the discussion of organic sludges (see Figure III-G-2). In view of the large amounts of lime used in high-lime treatment, recalcination would probably be employed. This has been reviewed in Section III-F-4. Recalcination, a recovery operation with respect to lime, is an incineration operation with respect to the organics in the sludges. The proportion of ash residue that would require subsequent disposal would be at least 50 percent, this representing about one-third of the original lime sludge dry solids.

8 - Land Disposal of Toxic Solids

As previously indicated, these wastewater solids are not now removed from the combined wastewater process stream. Nor is their removal from the wastewater stream expected in the future. Current trends throughout the State in the establishment of industrial waste control ordinances are intended to keep toxic materials out of the municipal waste system. It is proposed that they will be treated at the source and handled separately. No general quantity estimates have been made for these solids. Toxic solids typically include phenols and heavy metals; 80 and 40 percent, respectively, are expected to be removed with the organic sludges in conventional secondary level treatment. The year 2000 estimated removals of gross heavy metals will average 9.6 dry tons per day region-wide, this amounting to 11.8 dry pounds per million gallons.

a. Burial or Sanitary Landfilling

Pretreatment. Burial is probably the major method of disposing of toxic solids on land (Refs. 6,9,24,31,192,193,206). Pretreatment operations can include any of the following (Refs. 6,9,24,36):

1) Evaporation
2) Coagulation and precipitation
3) Sand filtration
4) Ion exchange
5) Electrodialysis
6) Metallic displacement or scrubbing
7) Differential volatility

8) Electrolytic separation
9) Solvent extraction
10) Biological Processes
11) Crystallization
12) Incineration

Storage as a method is particularly applicable to radioactive wastes. The length of storage time is designed to ensure a reduction in the level of contamination to non-toxic levels. Encasement in concrete before burial is often employed in the case of radioactive wastes.

Specific Site Criteria. The disposal of toxic solids requires Class I disposal sites or equivalent separate sites. The criteria associated with such sites have been discussed in Section III-G-2b. As indicated in Section III-G-2c, toxic solids must be buried. Specific site criteria are outlined in Section III-G-2c.

b. Deep-Well Injection

A general discussion on deep-well injection has been previously made in Section II-G-6b. The applicability of this method to radioactive wastes has already been observed (Refs. 203,206).

The pretreatment operations cited in the previous Section III-G-8a concerning burial of toxic solids and particularly radioactive wastes are applicable to deep-well injection. Slurrying with grout is one specific applicable preparatory operation.

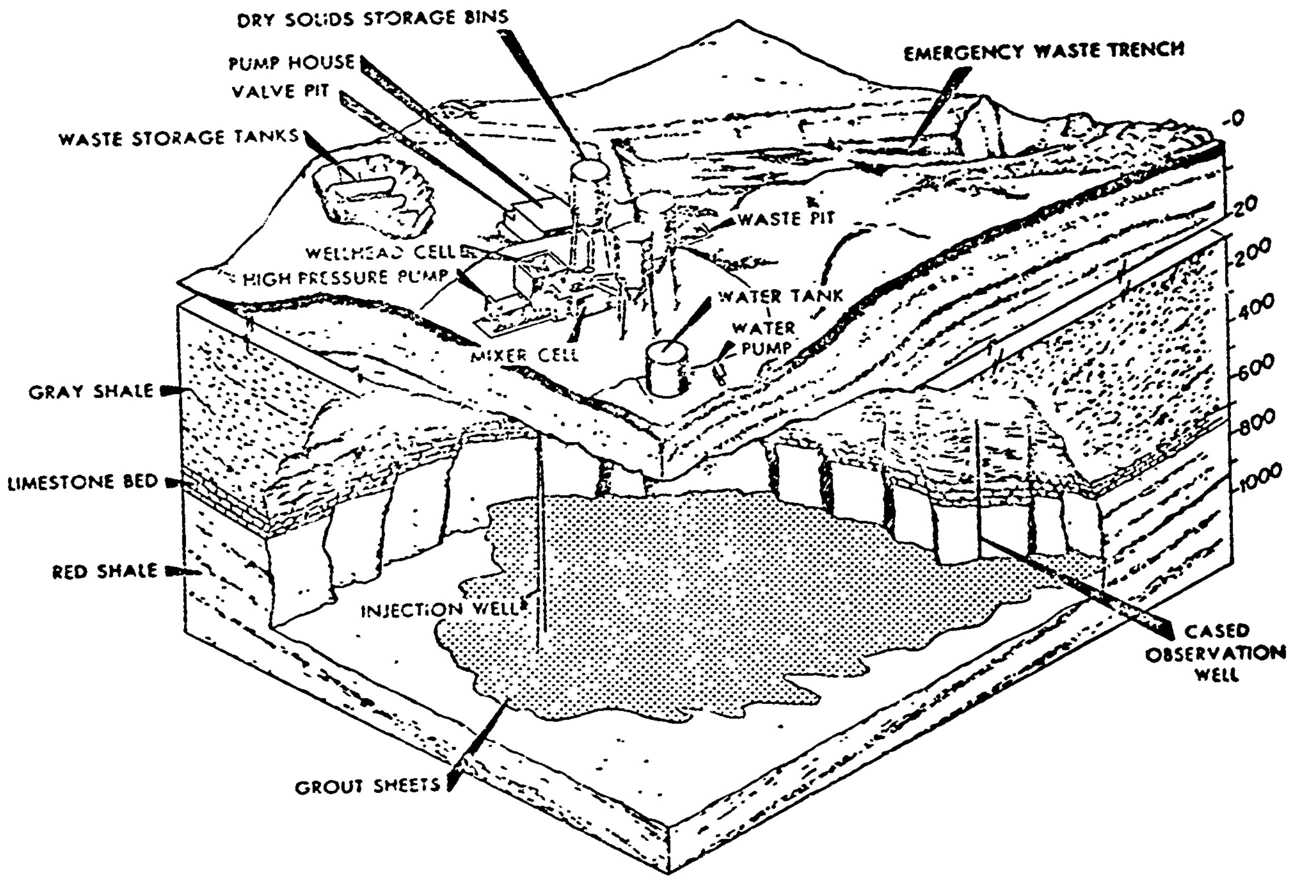
At the Oak Ridge National Laboratory in Tennessee (Refs. 203,206) radioactive wastes in a grout slurry are injected underground. This method has the advantage of fixing this waste in a solid form at known locations. Shales at depths of about 1000 feet are hydraulically fractured. A well is drilled and at the desired depth in a highly bedded shale, the fly ash radioactive waste slurry is injected at a pressure of 1700 and 2500 psi. It is reported that 1000 gallons of the mixture have been injected in an 8-hour pumping period. The result is an underground "pancake" which may average 0.1 inches in thickness and cover an area of several acres. The injection level is far below the usable groundwater strata and is separated from it by formations of nearly impermeable shale. Figure III-G-4 illustrates this process.

c. Miscellaneous Disposal Methods

Other land application methods are suitable for the disposal of toxic solids to the extent that toxic solids are mixed with other residual solids and essentially become non-toxic.

9 - Land Disposal of Regeneration Solids

Regeneration solids would be a minor fraction of combined municipal and industrial wastewater solids where physical-chemical and/or tertiary treatment is employed. They would invariably be recycled back into the plant



Oak Ridge National Laboratory disposes radioactive wastes in a cementitious slurry, which is injected into man-made fractures in shale beds deep underground.

DEEP-WELL INJECTION OF RADIOACTIVE WASTES

Figure III-G-4
(Ref. 203)

inflow for ultimate removal from the process stream with the organic, lime, or other chemical sludges. It is estimated that in the project year 2000, about 150 dry pounds per million gallons maximum could be involved, this corresponding to a region-wide average of 120 dry tons per day. The maximum would be involved with the employment of effluent filters.

10 - Environmental Impact Assessment

The principal environmental impacts of the various forms of land applications of wastewater residual solids are the direct effects on water quality and public health. These have been discussed with respect to dry and wet spreading of organic sludges. They have been dealt with implicitly in the selection of site and operational criteria. The concern of the latter includes potential impacts on aesthetic sensibilities and the problem of potential nuisances. Most adverse environmental impacts can be avoided or minimized by appropriate design and management of various land application operations.

The various methods of land disposal of wastewater residual solids involve no irreversible commitment of resources. Most of the methods of land application can be terminated if warranted by circumstances.

The opportunity to reclaim wastewater solid wastes for useful purposes is fundamental in the disposal systems and operations outlined. These methods illustrate the possibilities that exist for the beneficial utilization of waste materials by proper solid waste management.

The greatest opportunity of converting adverse environmental impacts to benefits lies with the increasing emphasis on reclaiming the residual wastewater solid "wastes." This is the objective of many of the "disposal" method which have been investigated.

STATE OF CALIFORNIA
REGIONAL WATER QUALITY CONTROL BOARD
SAN FRANCISCO BAY REGION

RESOLUTION NO. 69-42

STATEMENT OF POLICY WITH RESPECT TO REGULATION OF WASTE DISPOSAL ONTO LAND IN THE SAN FRANCISCO BAY REGION

WHEREAS, this Regional Board considers solid and liquid waste disposal operations onto land as waste discharges under the Water Quality Control Act, Division 7, California Water Code and recognizes that these operations may cause nuisance or have a deleterious effect on surface and ground waters of the State; now

THEREFORE BE IT RESOLVED, this Regional Board adopts the following as its policy with respect to regulation of waste disposal onto land in the San Francisco Bay Region:

CLASSIFICATION OF SOLID WASTE DISPOSAL SITES

Disposal sites will be classified on a case-by-case basis at the time waste discharge requirements are established for individual operations utilizing the attached "Classification of Solid Waste Disposal Sites" as a guideline.

Persons operating or proposing the operation of solid waste disposal sites will be responsible for conducting the geological and hydrological investigations necessary to classify the site and to demonstrate that the disposal of waste will not cause or threaten to cause pollution of the waters of the State.

MINIMUM REQUIREMENTS

The following minimum requirements will be considered at the time waste discharge requirements are adopted and dischargers without requirements are expected to use them as a guide in conducting their operations:

1. Decomposable organic material acceptable at Class I or II sites shall not be placed in water or in a position where it can be contacted by water nor shall it be placed in such a manner that leachate or gas generated from such material can adversely impair the quality of the waters of the State.

2. Surface runoff from adjacent areas shall be diverted from Class I and II sites.

3. Atmospheric odors recognizable as being of waste origin shall not occur at any place outside the disposal site.

4. Waste material shall not be in any position where it is, or can be, carried from the disposal sire and deposited into waters of the State.

LOCAL AGENCIES RESPONSIBILITIES

Local agencies are requested to:

1. Withhold new permits for solid waste disposal operations until waste discharge requirements have been established by the Regional Board.

2. Include in permits for solid waste disposal operations the provision that the permit will be subject to review and may be revoked upon the request of the Regional Board at the time a cease and desist order is issued pursuant to Section 13060 California Water Code.

3. Adopt and enforce minimum standards for the design, construction, operation and maintenance of solid waste disposal sites. Standards for operations in marsh and tideland areas should provide for watertight and stable dikes and for effective dewatering of disposal areas receiving Class I and II materials at all times.

This Regional Board is anxious to work with local agencies in the development of minimum standards for the design, construction, operation and maintenance of solid waste disposal sites and instructs the staff to assist local agencies in the development of these standards.

WILLIAM C. WEBER
Chairman

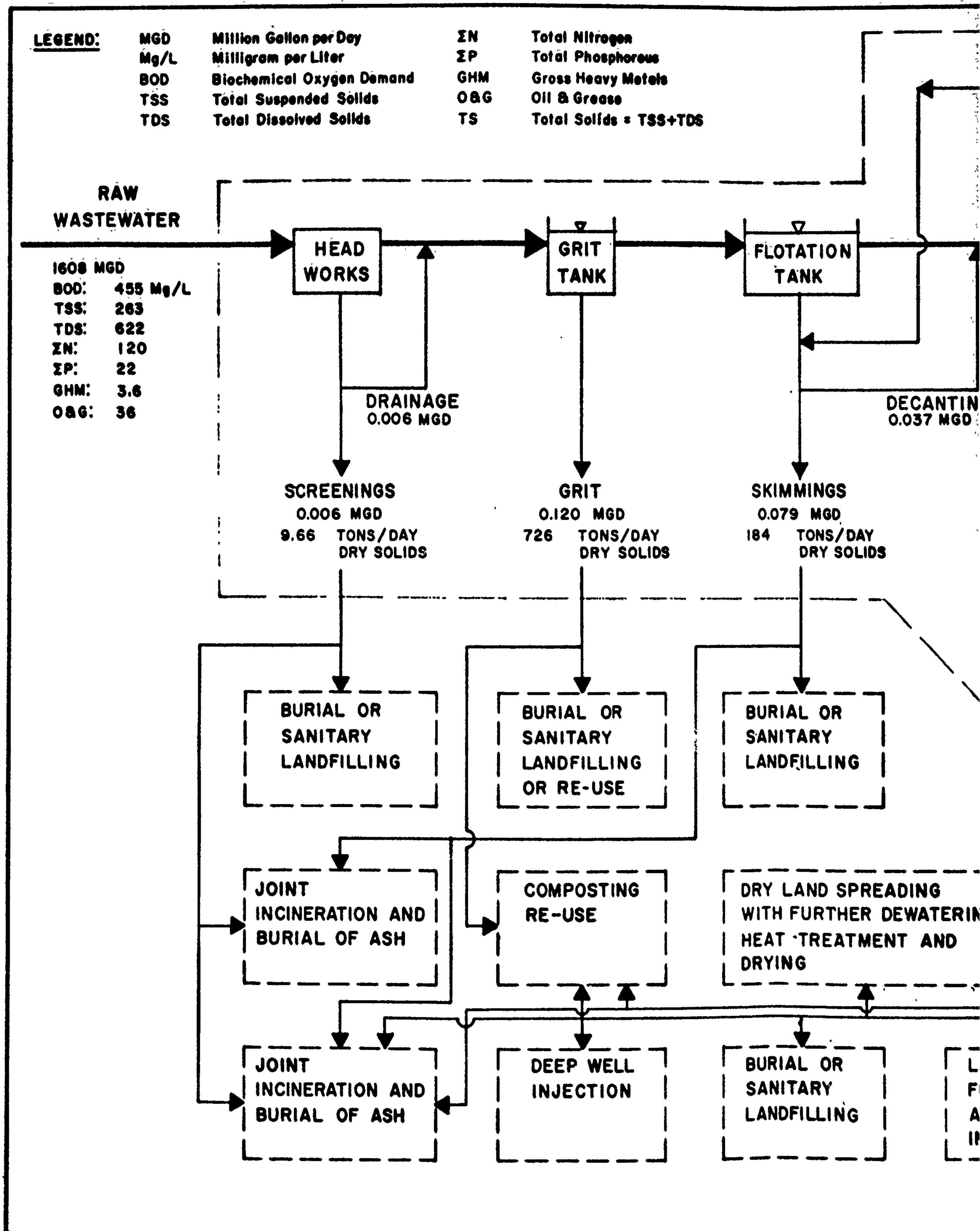
September 25, 1969

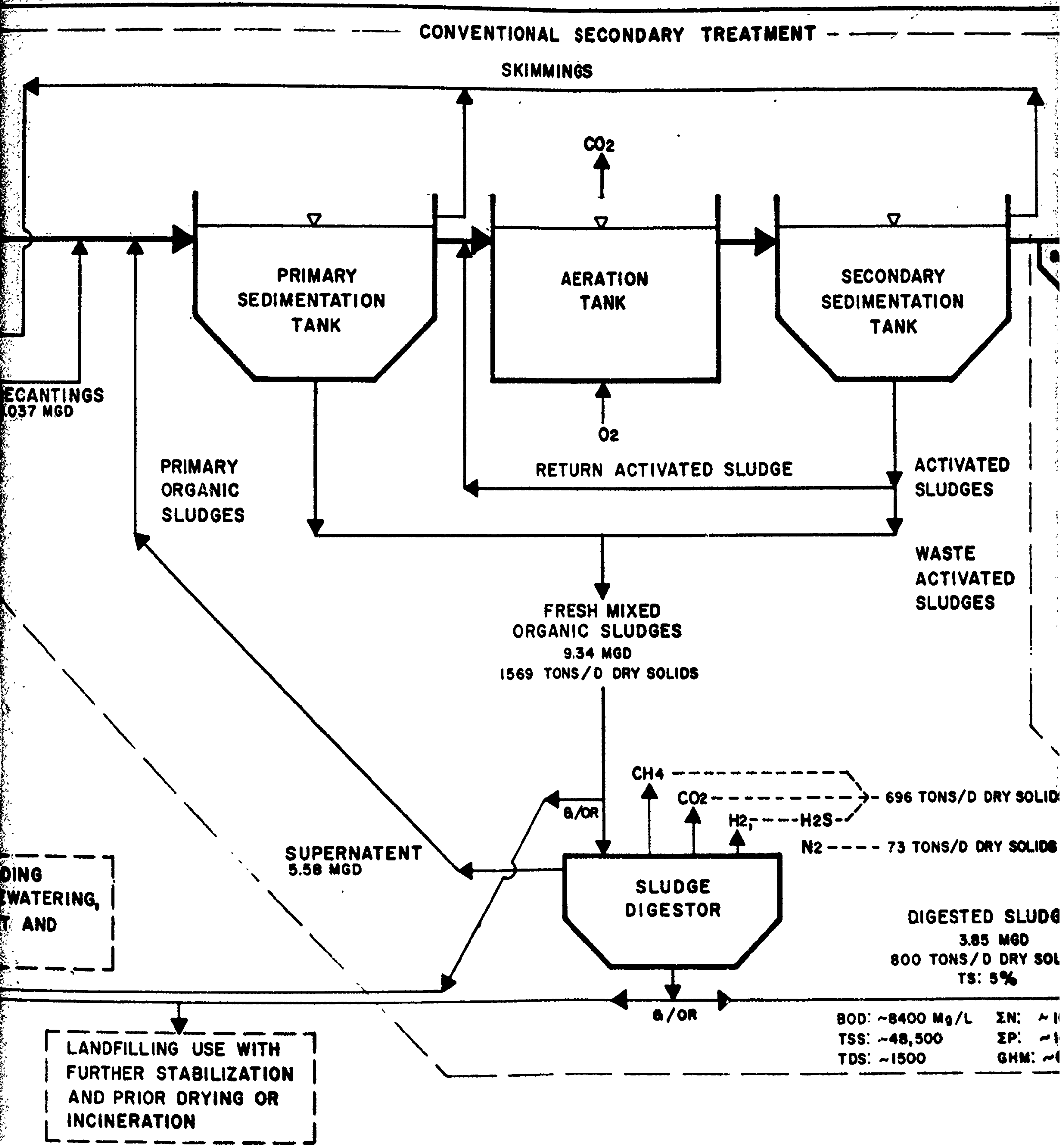
I, Fred H. Dierker, hereby certify that the foregoing is a true and correct copy of Resolution No. 69-42 adopted by the Regional Water Quality Control Board of Region No. 2 at its regular meeting on September 25, 1969.

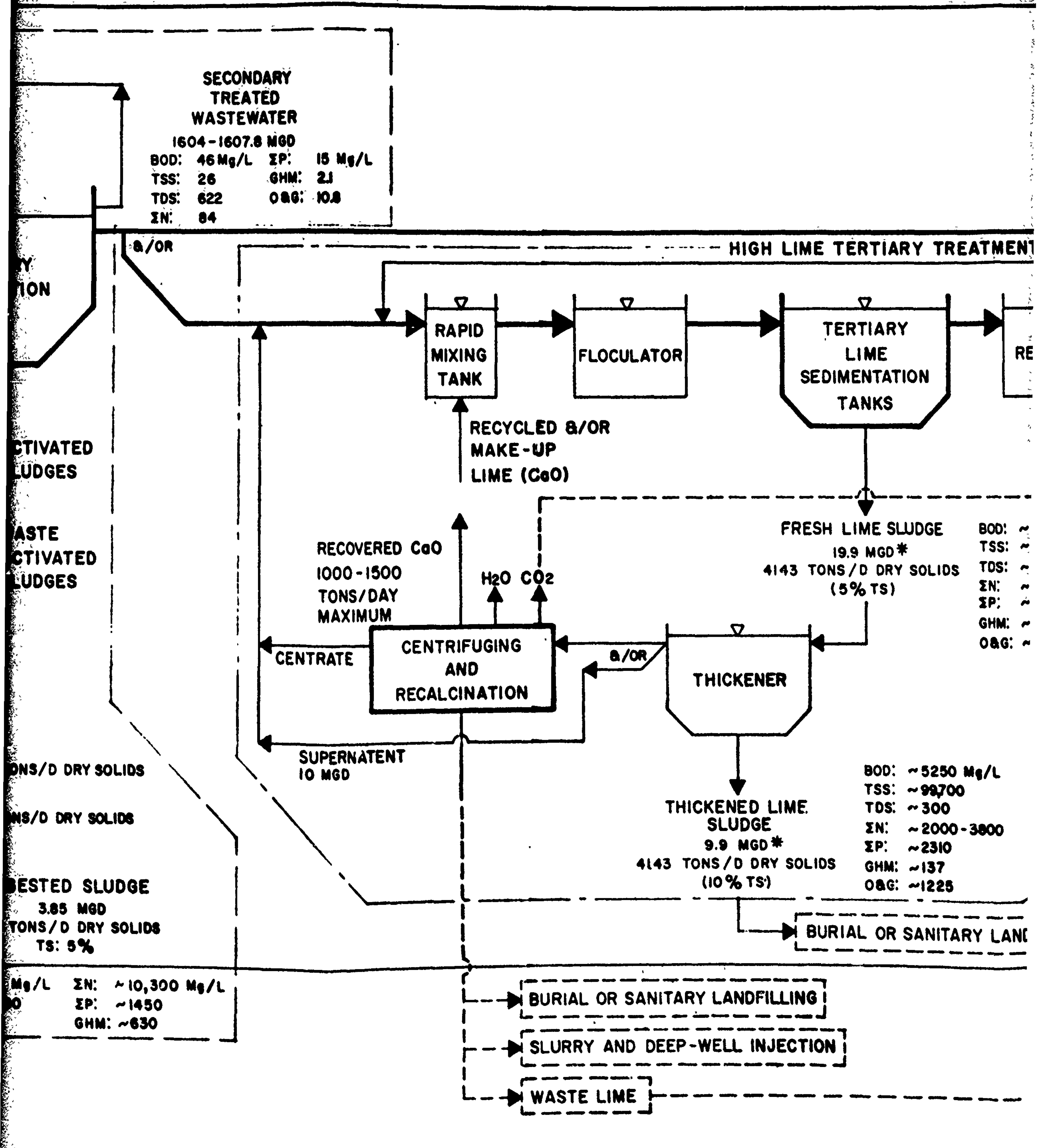
FRED H. DIERKER
Executive Officer
REGIONAL WATER QUALITY CONTROL BOARD NO. 2

CLASSIFICATION OF SOLID WASTE DISPOSAL SITES

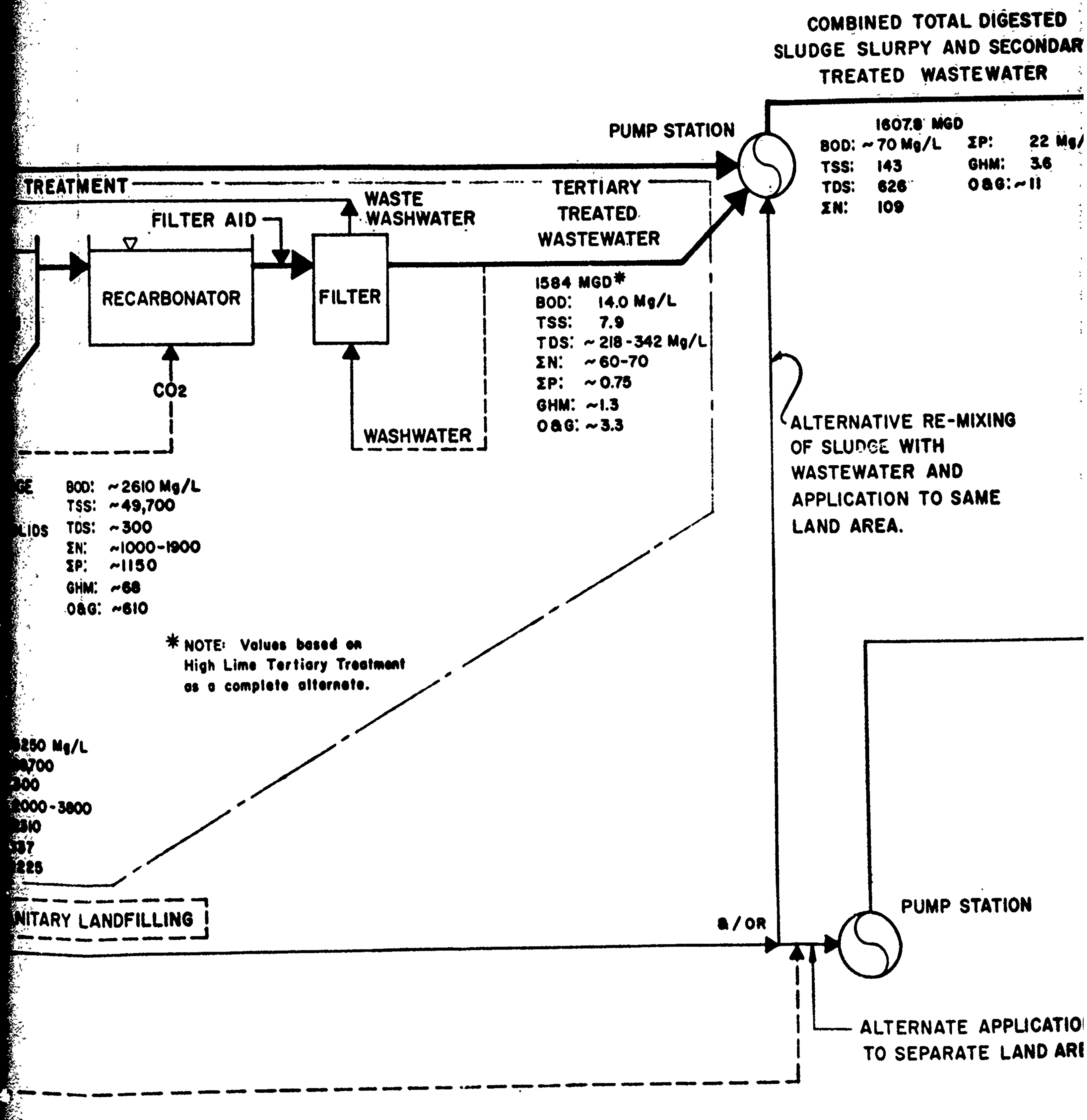
SITE CLASSIFICATION	GEOLOGICAL, HYDROLOGICAL AND TOPOGRAPHICAL CHARACTERISTICS	FACILITIES AND OPERATION	ACCEPTABLE MATERIALS
CLASS I	Sites located on nonwater-bearing rocks or underlain by isolated bodies of unusable groundwater, or where there shall be no seepage to usable waters. Sites having stability with respect to foundation, slope and embankments.	Adequate facilities to divert surface runoff from adjacent areas and to protect the exterior of the site from flooding and erosion. The site must be dewatered before commencing placement of readily-decomposable waste materials. Waste materials and all internal surface drainage restricted to the site unless requirements are adopted for a waste discharge.	No limitations on type of material, liquid or solid. Certain very toxic chemicals may require special handling techniques to provide long-term protection to public health and the environment.
CLASS II	Sites underlain by usable, confined or free groundwater where the lowest elevation of the disposal site can be maintained above the highest groundwater elevation. The distance shall be determined on a case-by-case basis. Sites having stability with respect to foundation, slope and embankments. Sites located over confined groundwater may be suitable for the disposal of designated industrial wastes if (1) the lowest site excavations are maintained above the elevation of the confining strata, (2) hydraulic continuity does not exist between any water above the confining strata and the confined groundwater, and (3) the confining strata will provide adequate protection of the confined groundwater.	Adequate facilities to divert surface runoff from adjacent areas, to protect boundaries of the site from erosion, and to prevent any conditions that would cause drainage from the materials in the disposal site. The site must be dewatered before commencing placement of readily decomposable waste materials. Surface runoff and internal drainage must be controlled and discharged pursuant to adopted waste discharge requirements. Floatable material shall not be in any position where it is, or can be carried from the disposal site and deposited into waters of the State.	Decomposable organic materials such as listed below and all materials acceptable at Class III sites: Municipal wastes - garbage, rubbish, mixed refuse, street refuse, abandoned vehicles, decomposable demolition material. decomposable construction wastes, sewage treatment residue, water treatment residue, manufactured rubber products, human fecal matter. Agricultural wastes - stalks, vines, prunings, manures, waste livestock feed, dead animals. Industrial wastes from - lumber and wood products, meat and poultry packing; tallow production and poultry hatcheries; production of beer, wine and spirits, fruit and vegetable packing, miscellaneous metals and metal products except magnesium and its alloys, and paint sludge.
CLASS III	Sites located so as to afford little or no protection to underlying groundwater. Sites located where solid wastes may contact adjacent surface water.	The operation of the disposal site must confine the solid wastes to the disposal area and must prevent erosion, siltation or other distribution of waste materials from the disposal site to the surface water.	Limited to solid inert materials such as: natural earth, rock, sand and gravel, paving fragments, concrete, brick and masonry, plaster and plaster products, inert demolition and construction materials, steel mill slag, glass, asbestos fiber and asbestos products, inert plastics.


LEGEND:
MGD Million Gallon per Day
Mg/L Milligram per Liter
BOD Biochemical Oxygen Demand
TSS Total Suspended Solids
TDS Total Dissolved Solids
ΣN Total Nitrogen
ΣP Total Phosphorous
GHM Gross Heavy Metals
O&G Oil & Grease
TS Total Solids = TSS+TDS
RAW WASTEWATER
1608 MGD
BOD: 455 Mg/L
TSS: 263
TDS: 622
ΣN: 120
ΣP: 22
GHM: 3.6
O&G: 36
HEAD WORKS
GRIT TANK
FLOTATION TANK
DRAINAGE 0.006 MGD
DECANTIN
0.037 MGD
SCREENINGS
0.006 MGD
9.66 TONS/DAY DRY SOLIDS
GRIT
0.120 MGD
726 TONS/DAY DRY SOLIDS
SKIMMINGS
0.079 MGD
184 TONS/DAY DRY SOLIDS
BURIAL OR SANITARY LANDFILLING
BURIAL OR SANITARY LANDFILLING OR RE-USE
BURIAL OR SANITARY LANDFILLING
JOINT INCINERATION AND BURIAL OF ASH
COMPOSTING RE-USE
DRY LAND SPREADING WITH FURTHER DEWATERIN
HEAT TREATMENT AND DRYING
JOINT INCINERATION AND BURIAL OF ASH
DEEP WELL INJECTION
BURIAL OR SANITARY LANDFILLING

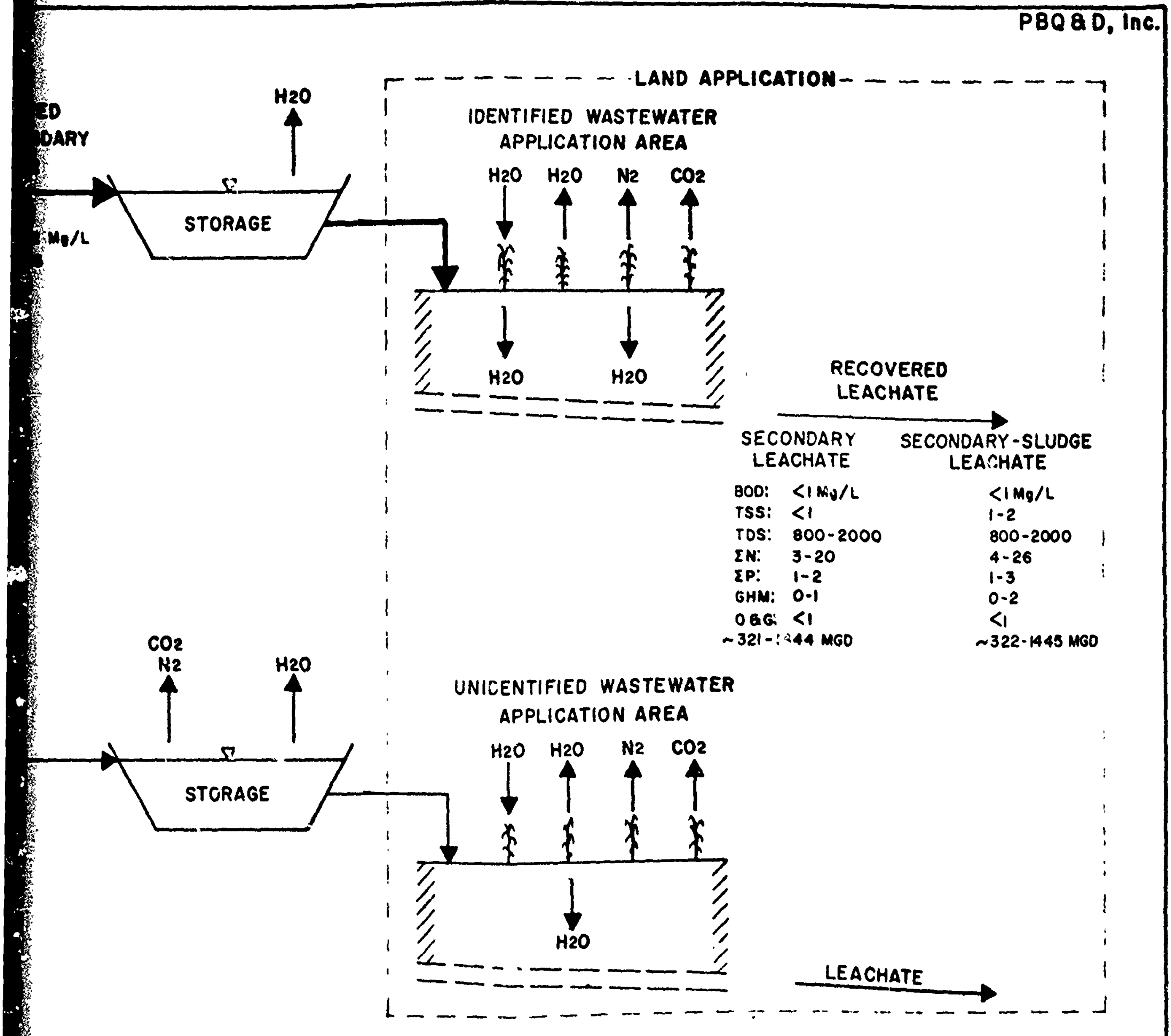

CONVENTIONAL SECONDARY TREATMENT
SKIMMINGS
CO2
PRIMARY SEDIMENTATION TANK
AERATION TANK
SECONDARY SEDIMENTATION TANK
ECANTINGS
.037 MGD
O2
PRIMARY ORGANIC SLUDGES
RETURN ACTIVATED SLUDGE
ACTIVATED SLUDGES
WASTE ACTIVATED SLUDGES
FRESH MIXED ORGANIC SLUDGES
9.34 MGD
1569 TONS/D DRY SOLIDS
CH4
CO2
H2
H2S
696 TONS/D DRY SOLID
N2
73 TONS/D DRY SOLIDS
a/OR
SUPERNATENT
5.58 MGD
SLUDGE DIGESTOR
DING
WATERING,
T AND
DIGESTED SLUDG
3.85 MGD
800 TONS/D DRY SOL
TS: 5%
a/OR
BOD: ~8400 Mg/L
TSS: ~48,500
TDS: ~1500
ΣN:
ΣP:
GHM:
LANDFILLING USE WITH FURTHER STABILIZATION AND PRIOR DRYING OR INCINERATION



SECONDARY TREATED WASTEWATER
1604-1607.8 MGD
BOD: 46 Mg/L ΣP: 15 Mg/L
TSS: 26 GHM: 2.1
TDS: 622 O&G: 10.8
ΣN: 84
&/OR
HIGH LIME TERTIARY TREATMENT
RAPID MIXING TANK
FLOCULATOR
TERTIARY LIME SEDIMENTATION TANKS
RE
RECYCLED &/OR MAKE-UP LIME (CaO)
ACTIVATED SLUDGES
WASTE ACTIVATED SLUDGES
RECOVERED CaO 1000-1500 TONS/DAY MAXIMUM
H2O CO2
FRESH LIME SLUDGE
19.9 MGD*
4143 TONS/D DRY SOLIDS
(5% TS)
BOD: ~
TSS: ~
TDS: ~
ΣN: ~
ΣP: ~
GHM: ~
O&G: ~
CENTRATE
CENTRIFUGING AND RECALCINATION
&/OR
THICKENER
SUPERNATENT 10 MGD
TONS/D DRY SOLIDS
TONS/D DRY SOLIDS
THICKENED LIME SLUDGE
9.9 MGD*
4143 TONS/D DRY SOLIDS
(10% TS)
BOD: ~5250 Mg/L
TSS: ~99,700
TDS: ~300
ΣN: ~2000-3800
ΣP: ~2310
GHM: ~137
O&G: ~1225
DIGESTED SLUDGE
3.85 MGD
TONS/D DRY SOLIDS
TS: 5%
BURIAL OR SANITARY LAND
Mg/L ΣN: ~10,300 Mg/L
ΣP: ~1450
GHM: ~630
BURIAL OR SANITARY LANDFILLING
SLURRY AND DEEP-WELL INJECTION
WASTE LIME



COMBINED TOTAL DIGESTED
SLUDGE SLURPY AND SECONDAR
TREATED WASTEWATER
PUMP STATION
1607.8 MGD
BOD: ~70 Mg/L
TSS: 143
TDS: 626
ΣN: 109
ΣP: 22 Mg/
GHM: 3.6
O&G: ~11
TREATMENT
TERTIARY
TREATED
WASTEWATER
WASTE
WASHWATER
FILTER AID
RECARBONATOR
FILTER
CO2
WASHWATER
1584 MGD*
BOD: 14.0 Mg/L
TSS: 7.9
TDS: ~218-342 Mg/L
ΣN: ~60-70
ΣP: ~0.75
GHM: ~1.3
O&G: ~3.3
ALTERNATIVE RE-MIXING
OF SLUDGE WITH
WASTEWATER AND
APPLICATION TO SAME
LAND AREA.
GE
LIDS
BOD: ~2610 Mg/L
TSS: ~49,700
TDS: ~300
ΣN: ~1000-1900
ΣP: ~1150
GHM: ~68
O&G: ~610
* NOTE: Values based on
High Lime Tertiary Treatment
as a complete alternate.
250 Mg/L
700
00
000-3800
310
37
225
NITARY LANDFILLING
&/OR
PUMP STATION
ALTERNATE APPLICATIO
TO SEPARATE LAND AR



CONCEPTUAL FLOW DIAGRAM

WASTEWATER AND RESIDUAL SOLIDS LAND DISPOSAL ALTERNATIVES

REGION-WIDE COMBINED MUNICIPAL AND INDUSTRIAL WASTEWATERS - YEAR 2000

(BASED ON CONVENTIONAL ACTIVATED SLUDGE TREATMENT SYSTEM)

Figure III-G-5

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H. BIBLIOGRAPHY

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